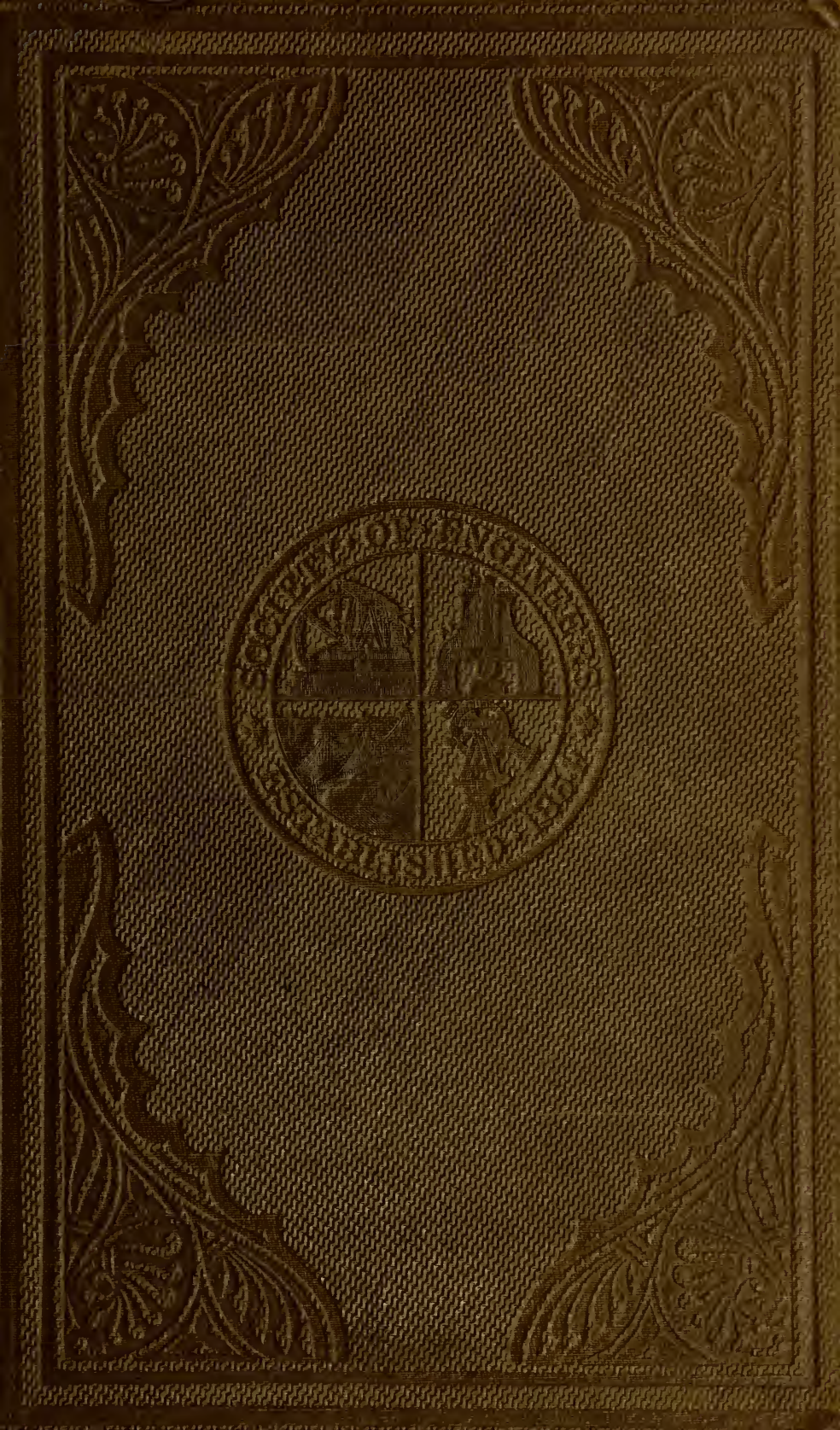

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SOCIETY OF ENGINEERS.

ESTABLISHED MAY 1854.

TRANSACTIONS FOR 1889,

AND

GENERAL INDEX, 1861 TO 1889.

EDITED BY

G. A. PRYCE CUXSON,

SECRETARY.

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PREMIUMS FOR 1889.

At a Meeting of the Society, held on the 3rd February, 1890, the following Premiums of Books were awarded, viz.:—

The President's Premium to:

G. M. Lawford, Assoc. M. Inst. C.E., for his paper on "Fireproof Floors."

The Bessemer Premium to:

Samuel Griffin, for his paper on "Modern Gas-Engine Practice."

A Society's Premium to each of the following gentlemen:

To Henry Faija, M. Inst. C.E., for his paper on "Forced Percolation of Water through Concrete."

To George R. Strachan, Assoc. M. Inst. C.E., for his paper on "The Construction and Repair of Roads."

McElroy
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CONTENTS.

PAGE

Inaugural Address of the President, Jonathan Robert Baillie, M. Inst. C.E. 1

The Construction and Repair of Roads. By George R. Strachan, Assoc. M. Inst. C.E. 17

Fireproof Floors. By G. M. Lawford, Assoc. M. Inst. C.E. .. 43

Recent Developments in High Explosives. By Perry F. Nursey, Past President 71

The Forced Percolation of Water Through Concrete. By Henry Faija, M. Inst. C.E. 107

Vacation Visits 131

Pin-Connected *v.* Rivetted Bridges. By James Henry Cunningham, Assoc. M. Inst. C.E. 135

Modern Gas-Engine Practice. By Samuel Griffin 169

Fox's System of Solid-pressed Steel Waggon and Carriage Frames By Perry F. Nursey, Past President 197

Obituary 219

Index 223

SOCIETY OF ENGINEERS.

ESTABLISHED MAY 1854.

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OFFICES:
17, VICTORIA STREET, WESTMINSTER, S.W.

PLACE OF MEETING:
THE TOWN HALL, WESTMINSTER, S.W.

1890.

TRANSACTIONS, &c.

February 4th, 1889.

INAUGURAL ADDRESS

By JONATHAN ROBERT BAILLIE, M. Inst. C.E.,

President.

In taking the chair for the first time as President of this Society, let me thank you most warmly for the honour you have conferred upon me in electing me to that position. It is, however, a position which I did not consent to accept without some hesitation, for I felt there were others who might occupy it with better advantage to our Society, by reason of their being able to give more time to its duties than I may be able to. However, you have been good enough to elect me your President, and I will do my best to carry out the duties of the office so that the Society may pass with credit throug the thirty-fifth year of its existence. As a member of the Society for twenty-five years I have had ample opportunity of knowing that in my endeavours to promote its interest I shall be loyally supported by the whole body of members, whilst my experience as a Member of Council teaches me that I can at all times count upon the hearty co-operation and assistance of the whole executive body. In this two-fold trust I gladly enter upon my duties, and hope that, at the end of my year of office, I may be able to place the charge you have committed to me into the hands of my successor, not only unimpaired, but, if I may venture to say so, improved.

My first idea of duty is that one should follow, not blindly but thoughtfully, in the steps of one's predecessors, so far as those steps tend to preserve the best traditions of the Society.

I will, therefore, in the first place (as has been the time-honoured custom), briefly review the work of the Society during the past year, and then proceed to notice the leading engineering enterprises of the present time, which have recently been completed or are in progress. With regard to our present position, I can only say it is very satisfactory, thanks largely to the zeal displayed by my immediate predecessor for the welfare of the Society. During last year we elected three Honorary Members, namely, Sir I. Lowthian Bell, Bart.; Sir Robert Rawlinson, K.C.B.; and Mr. W. H. Mahoney Christie, F.R.S. Of Ordinary Members we elected twenty-two, and of Associates twenty. Our muster roll shows that we have 414 Members and Associates all told, whilst a fair number are awaiting election. During last year the Council experienced a loss in the retirement, through ill-health, of our late Secretary and old friend, Mr. Charles J. Light. They have, however, been fortunate in securing the services of Mr. G. A. Pryce Cuxson, whose experience and energy are proving of great value to the Society. I would here ask the Members generally to second the efforts of the executive of the Society by introducing new members, by preparing papers for discussion, and by taking a personal interest in the working of the Society, both as regards the sessional meetings, and the vacation visits to works. Respecting these latter, nothing that I could say in their favour would be too strong, for they are simply invaluable to members, as giving them an insight into practical work. We must remember, too, that many of these works to which we are admitted as a body would be absolutely closed against individuals. I would, therefore, lay special stress on this important means of acquiring knowledge offered to members by the Society. I believe ours was the first Society to inaugurate these visits, and we should not forget that it was at the instigation of our worthy friend, Mr. Alfred Williams.

Turning to the papers read during the past year, we have first the thoughtful and interesting address of my predecessor, Mr. Arthur T. Walmisley, which was followed by a paper on the "Effect of Sea Water on Portland Cement," by Mr. Henry Faija, who three years previously gave us a paper on the general subject of that important constructive material. Mr. Faija's paper was founded upon the failure of some concrete work at Aberdeen graving dock, and the conclusions at which he arrived were that sea water has no deleterious chemical action on a sound and properly used Portland cement. He therefore attributes the failures at Aberdeen to some other cause. The next

paper was by Mr. W. Santo Crimp, who described the Wimbledon Main Drainage and Sewage Works. The paper was full of information upon the subject of which it treated, and will prove of great value to sanitary engineers engaged in such work, as a record of the method of dealing with, and disposing of, the sewage of a district of some 3,500 acres near London. The question of mechanical filtration was next brought before us by Mr. Edward Perrett, who discussed the relative advantages of various systems, and pointed out the merits of a system of his own, which is in use in South America. Here the filtering medium is crushed retort coke, which is effectually cleansed by the occasional application of an upward stream of compressed air. At the waterworks where this system is in use, 20,000 gallons of river water are filtered per hour, the area covered measuring 37 feet by 7 feet 6 inches, giving an average rate of filtration of nearly 100 gallons per square foot of filtering surface per hour. "The Acton Main Drainage Works," formed the subject of the next paper, which was read by Mr. C. Nicholson Lailey. A special interest attached to this paper, on account of its including a description of the ferro-carbon precipitation process, which system Acton was the first town to adopt. This process consists in the precipitation of solids, and the filtration of the effluent through a bed containing a layer of magnetic spongy carbon. This magnetic carbon is stated to possess very remarkable oxydising and aërating powers, so that the effluent is found to have a very high degree of purity imparted to it.

The vacation here intervened, but on resuming the meetings in October a paper was read on "Light Railways," by Mr. William Lawford. The author complained, and not unreasonably, that but little had been done as regards the construction of light railways in this country, and that that little had not proved commercially successful, owing to the want of due facilities as regards their construction and working. He held that, notwithstanding the powers conferred by the Railways Construction Facilities Act, still greater facilities should be afforded by the Government, in order to promote the development of light railways in this country. He showed what was being done in other countries in constructing and working light railways, and in making them pay. Therefore, he asked, if light railways could be made to pay in other countries, why should they not do so in this? And he argued that they could be made to pay if a fair chance were given. An interesting paper by Mr. H. Ross Hooper on the "Practice of Foundry

Work," followed at our next meeting. Mr. Hooper selected a very wide subject, but confined himself to the details of moulding and casting, which he treated in a practical manner, concluding his useful paper with some remarks upon the inspection of cast iron work, and the tests usually applied to and the general strength of cast iron. The final paper of the year was that by Mr. William Worby Beaumont, on "High Pressure Steam and Steam Engine Efficiency." This was a theoretical examination into the advantages attending the use of high pressures in steam engineering. The auther combated the supposition that the useful limit to steam pressure would be reached at about 200 lb. or below it, and he gave reasons for expecting a very large increase in available work, as due to the increase of pressure up to at least 300 lb. No more striking comment upon the high character of the whole of the papers read during the past year can be afforded than the fact that the Council awarded a premium of books to the author of every paper, which premiums have been presented this evening by the retiring President, as you have seen. I can only hope that the papers to be read before us during the present year will each merit similar recognition.

Our first vacation visit was made on June 26th, when, in large numbers, we inspected the works of the Tower Bridge. The inspection was most interesting and instructive, affording the members an insight into a special class of construction. We were first shown the building work in progress on the northern approach, after which, we steamed to the north pier, upon which we landed, and saw the work of construction going on inside the caissons, the work then being nearly up to high-water level at that point. We were then conveyed to the south pier, where the constructional work was proceeding in some of the caissons, and the excavation in others. In the following month we visited the precipitation works in progress at Barking sewage outfall. These works comprise a series of covered precipitation tanks, in which the sewage will be treated by lime and iron, the effluent being afterwards discharged into the river at suitable times of the tide. The sludge is to be discharged into ships, which are to convey it out to sea and there deposit it. The works extend over an area of about fifty acres, and the quantity of sewage to be dealt with is about 90,000,000 gallons per day.

Our third and last vacation visit, made in September, was to the locomotive and carriage works of the London and South-Western Railway at Nine Elms. Those members who had

joined in the previous visit to these works in 1880 were able to realise the extensive alterations, additions, and improvements which have been effected since that time by our old friend and past president, Mr. William Adams, who is the locomotive superintendent of the South-Western Railway. These works were originally designed by the late Mr. Joseph Beattie, the former locomotive superintendent of the company, and at the time of their erection they were considered to be very complete, and were fully adequate to the then requirements of the South-Western system. Owing, however, to the increase of traffic, and of rolling stock, it was found necessary to alter and enlarge them throughout, which has been very efficiently done. The works now cover 45 acres of land, and afford employment to between 2,000 and 2,500 men. They are very comprehensive, and are most complete in every respect. In concluding my remarks upon the subject of our vacation visits, I can only repeat that they are of the highest value and importance to members, as affording them the means of obtaining a practical insight into works of construction and of production of very varied character which, for the most part, would otherwise be closed against them.

The recent progress of electric lighting is worthy of a passing glance, in respect to central station lighting, inasmuch as we have in course of construction near London one of the largest central stations ever attempted. The building, which is situated at Deptford, is about 200 feet square, and 100 feet high, and constitutes the combined engine, machinery, and boiler house for the central lighting station of the London Electric Supply Corporation. The object is to supply London with the electric light, and with this view the corporation have laid down lines for the eventual supply of two millions of lights. From this great central station they propose to convey the electric current to all parts of the metropolis. For the present, however, the plant and machinery being erected is for the supply of 250,000 glow lamps. The boiler house is constructed to contain boilers having an aggregate of 65,000 horse-power. Of these boilers, which are of the Babcock and Wilcox type, a number are now being erected, which will supply steam for engines of 13,000 horse-power. The first engines, which are being made by Messrs. Hick, Hargreaves, and Co., of Bolton (who are to supply the remaining engines and machinery), will be a pair of 3000 combined horse-power. They are of the compound Corliss type, and are to drive two Ferranti dynamos, each capable of generating the current for 25,000 glow lamps. These

are what are called the small machines, the larger ones yet to come are each to weigh 400 tons, and to have an armature 40 feet in diameter. These dynamos are to be driven, each by a pair of engines of 10,000 horse-power, but at first it is intended that only half that power shall be developed for driving each dynamo, which will primarily supply the current for 100,000 lights. When more light is demanded, each dynamo is to be driven by the full power of its engine, and each will then supply the current for 200,000 lamps. The current, which is an alternating current, and is generated at high tension, is to be conducted from Deptford to various parts of the metropolis by means of an arrangement by which, it is said, loss will be prevented, and absolute safety insured. The current is to be delivered in London at several points, where distributing stations are to be established. Here the current will be converted into one of lower tension by means of transformers, and it will be distributed from the stations to the public at medium tension by subsidiary mains, and finally converted or expanded to low tension by transformers on the premises of each consumer. This is a gigantic undertaking, and one cannot help wondering what will be the effect of sending to London this enormous current, which is to have an electromotive force of 10,000 volts. The Electric Supply Corporation, however, appear to entertain no anxiety upon this point. They have for some time past run the Grosvenor Gallery station, from which they are supplying the current to some 33,000 lamps, over an area extending from Regent's Park on the north to the River Thames on the south, and from Knightsbridge westward to the Royal Courts of Justice eastwards.

Besides the colossal generating station at Deptford, there are several belonging to other companies, which are either at work or in course of construction in the metropolis. For instance, the system of distributing electricity by means of the Gaulard-Gibbs secondary generator is being adopted at a central station near Lincoln's Inn, while another station has recently been opened at Kensington. This station was officially opened on January 24th, this year, with a partial installation. The works adjoin the West Brompton Station of the Metropolitan District Railway, and have a depth rearwards of 470 feet. The engine and dynamo house form the central portion, a boiler house being erected at each end. The present installation consists of three sets of dynamos and engines, each set being capable of generating the current for 4000 glow lamps. The completed stations will contain twelve sets of such plant, having a capacity

of 48,000 glow lamps. The dynamos are of a special type, known as the "Lowrie-Parker," and they are driven by engines by Fowler and Co., of Leeds, taking steam from Babcock and Wilcox boilers. The primary current is of high tension, which is converted into one of low tension at each house to be lighted by it, by means of Lowrie-Hall converters.

The reason of these marked advances, which are in the direction of house-to-house lighting, is to be found in the passing of the Electric Lighting Act Amendment Bill. That event at once gave an impetus to enterprise in this direction, and it witnessed a rapid revival of projects for conferring on the public the benefits obtainable from electricity as a source of light. There was a general resuscitation of undertakings already in existence having for their object the distribution of the electric current from central stations, whilst several new enterprises of a similar character were started with a view of carrying out this object in various parts of the metropolis. The stringent clauses of the Electric Lighting Act were very necessary in the first instance, for preventing the creation of an injurious monopoly and the formation of bogus companies. The Amendment Bill, however, was a just and reasonable concession, the time having arrived when the way should be made easier for legitimate enterprise. The greatest caution was necessary, too, at first, in preventing power from getting into irresponsible hands, in view of the public safety as regards what could only then be considered as an undeveloped system. Although we have got farther now, we are still a long way from having wrested from nature all the secrets of that mysterious power, electricity.

There was a time when the Manchester Ship Canal was looked upon as a mere chimera, a bogey invented to frighten down railway rates between Liverpool and Manchester. That was at the date of its inception, but as time went on, and witnessed the plucky fights in Parliament, those who came to sneer remained to fear, realising that there was a reality and a business-like character about the matter which they had not anticipated. Since the Bill was passed, a strong current in favour of this means of inland transport has set in. Hence various old canal projects have been revived, and numerous new ones have been started, but as yet without any great practical results. The establishment of such sources of intercommunication, however desirable, is beset with several difficulties, especially when viewed in the light of competition with railways. It must be remembered that the railway companies own a number of canals, which, as a matter of policy

or, for other reasons, they have had to acquire. It is not likely they will part with these, and, as a rule, where they coincide with the routes of their lines, the railway rates are kept as high as they reasonably can be. On the other hand, where canals not owned by the companies compete with them, their tariffs are lower. Where canals do not at present exist, higher prices rule, which would, no doubt be reduced were canal competition started. It, however, seems hardly feasible that we should go back to inland canal navigation, except perhaps, in very special instances, where important seaports and great commercial interests are concerned, as in the case of the Manchester Ship Canal, the credit of bringing which to the construction stage is due to Mr. Daniel Adamson.

Touching the progress of this canal, I may mention that, although work was only commenced in November, 1887, there is now a contractor's line throughout the whole length, and a very large quantity of the excavation of the Mersey portion, commencing at Eastham has been completed, and excavation is progressing along nearly the whole length of the route. This rapid rate of progress is due to the energy of Mr. T. A. Walker, the contractor for this undertaking. There are over 10,000 men and boys engaged on the canal, the greater portion of them being occupied in Cheshire. The sections of the canal to Runcorn are more advanced than the remainder to Manchester. The plant at present on the contractor's railway consists of 144 locomotives and 4,700 waggons. The excavations are being carried on mainly by eighty-nine steam diggers, which do their work exceedingly well. The docks at the entrance of the canal into the Mersey have been excavated, and the lock-gates will shortly be fixed in place. The canal will be 35 miles in length, and the largest basin will be 600 feet long and 400 feet wide, with a depth of about 40 feet. The following is a statement with which I have been favoured by Mr. E. Leader Williams, the engineer of this undertaking, showing the number and types of steam navvies, locomotives, engines, steam cranes, and waggons, at work, and the number of miles of temporary railway laid to the present time :—

Steam navvies, French Buette	2
Steam navvies, German Lubecker	3
Steam navvies, Ruston and Proctor	60
Steam navvies, other makers	24
Locomotives	144
Portable and other engines	95
Steam cranes	91
Earth and ballast waggons	4700
Miles of railway laid	170

Another work of a similar character to that just discussed is making good progress. This is the canal which is being made across the Isthmus of Corinth. It will be about 4 miles in length from sea to sea, and was to have a width at top of 131 feet, but it has been found necessary to increase the slope on either side to prevent landslips, and, in places to protect the sides by building up. Originally it was estimated that there would be 8,000,000 cubic metres to be excavated, at a cost of 1,200,000*l*., including 5 per cent. interest per annum to the shareholders, and that the cutting would be completed last November. Now, owing to necessary increase of slope, it is reckoned that 10,000,000 cubic metres require to be extracted, and that the cost will be increased to 2,400,000*l*. The width at the bottom and the depth is to be the same as the Suez Canal, viz. 72 feet and 26 feet respectively. At the western end of the canal, on the Gulf of Corinth, are the depot and offices of the canal company, around which a new town is growing up, and to which the name of Isthmia has been given. The largest docks will be at the eastern end. It is expected that the work will be completed about two years and a half hence.

The commencement of the construction of the Manchester ship canal initiated a kind of craze for this means of carrying on the transport of merchandise. Numerous schemes were proposed, some of which met with but a cool reception, while others received some attention. Among the proposals of this latter class is one for constructing a ship canal between the Bristol and English Channels, whilst another scheme is for a ship canal across Scotland. The route decided on for the English canal is from Stolford in Bridgwater Bay, passing through the towns of Bridgwater, Langport, Ilminster, and Chard, to Seaton on the English Channel. The total length of the canal will be about 45 miles, and with the exception of the Chard range of hills, the work of construction for the whole distance is reported to be of a comparatively light character, no engineering difficulties presenting themselves. The canal is to be in every way capable of admitting the largest mercantile steamer afloat, as well as ships of war. From a national point of view, this canal would appear to be of considerable importance, as our ironclads could steam across from one channel to the other in a couple of hours or so, instead of having to go round Land's End, as at present. The trade of South Wales would also be benefited by such a canal, inasmuch as goods shipped to London and the Continent would save some 300 miles, and avoid the risk incidental to coasting. With

regard to Scotland, it is proposed to improve the existing canal between the Clyde and the Forth, so that ships may be able to pass through. This canal is 35 miles long, and extends from Bowling on the Clyde to Grangemouth on the Forth, and there is a branch of $2\frac{3}{4}$ miles to Port Dundas, in the north of Glasgow. The canal rises 156 feet, and has 39 locks, which are short, and there is only about 9 feet of water, so that large vessels cannot now use the route. It is proposed to make the canal suitable for deep sea-going ships, at a cost of about 2,000,000*l*. It is contended that, being the shortest route to America from the Baltic, the Continent, and the east coast of Scotland and England, the through traffic would be considerable. There are, of course, other sides to the question, including the character of the tidal approaches, and it is problematical whether such a canal could be made to pay. The canal mania appears to have reached Sweden, in which country a canal has been projected to connect the Kattegat with the Lake of Venern. It will also connect the towns of Uddevalla and Gennersborg, and will be about 12 miles long, 4 miles of lakes on the route being utilised. If carried out, this canal will doubtless prove of importance to a large portion of middle Sweden, where a number of ironworks are located. The depth of water in Uddevalla harbour will limit that of the canal to 21 feet, which would admit of vessels of about 3000 tons using the canal.

Before quitting the subject of canals, I may refer to the threatened collapse of the Panama scheme, which appeared somewhat imminent at the close of last year. It would be a great pity if it were allowed to collapse, after so much time and money have been spent upon it, and after so much good work has been done. So far M. de Lesseps' great scheme has cost about 46,000,000*l*., the money having all been subscribed by the French people. In some respects the management is to blame for financial mistakes, such as paying interest to share and debenture holders. But the bulk has been spent upon the undertaking, and there is plenty to show for the amount expended, considering the climate, the nature of the work, and the character of the workmen. It is to be hoped, however, that the threatened collapse will be averted by the prompt action which has been taken in the matter. It would appear that about 20,000,000*l*. more are required to complete the undertaking, and if those interested in it do not lose heart, we may hope to hear of the necessary funds being subscribed in due course. France has hitherto shown herself to be most

elastic in respect of raising money when urgently required, and it is to be hoped, in the interest of the supporters of the Panama Canal, that she will not forfeit her good name in this connection.

Among the much-needed works of utility nearer home is the Greenwich Ferry, which will greatly facilitate the below-bridge traffic between Greenwich and the Isle of Dogs. It is not perhaps generally known that a charter was granted in 1626 for this ferry for horses and vehicles. This shows that the necessity for intercommunication between the two banks of the river existed two centuries and a half ago, although, of course, not nearly to so great an extent as it does now. It will be seen how great the present necessity is, when it is pointed out that there is no means of crossing the river by vehicles east of London Bridge, and that the whole of the heavy traffic from the factories, works, docks, and arsenals on either side has to take the London Bridge route. This involves, in the case of traffic from one side of the ferry to the other, a journey of some seventeen miles. There are several novel features in the design of the steamers and piers for this ferry. The vehicular traffic will be placed on and taken off the steamers on the level at all states of the tides. Rails will be laid down for the reception of railway trucks, and the steamers are designed to carry fourteen vehicles each trip. It is expected that this ferry will be opened next month.

An event of considerable interest and importance to China was the opening of the Tientsin Railway in October last. Steamboats were placed on Chinese waters about thirty years ago, and ever since that time the introduction of railways has been a favourite topic. The first railway in China was the Shanghai and Woosung, which was opened and worked in 1876, but its hopeful career was unfortunately closed in 1877. It came to an untimely end through a violent attack of Chinese prejudice and apathy, from which, however, it had more or less suffered from the first. It is to be hoped that the Tientsin railway may be able to give to history a better account of itself, and that it may prove the precursor of a regular system of railways in China. Judged by the light of recent events, however, there does not appear much hope of this state of things being brought about at present. Within the last few days, news has been wired from China that a proposed extension of the Tientsin railway to Tung-Chow has encountered an unexpected obstacle, which, it is to be feared, will prove fatal to its progress, for the present at least. The great fire, which

destroyed part of the imperial palace, in Pekin, on January 17, caused much disturbance in the minds of the old-fashioned and superstitious, who are still strong in the capital. In consequence, the emperor and his mother consulted the imperial astrologers, who, after much deliberation, declared that the fire was an evil omen, and was intended as a warning against permitting the approach of the "western invention" to the sacred city. The further extension of the railway has, therefore, it is reported, been prohibited by imperial decree.

A very remarkable piece of work at present in hand is the Nova Scotia Ship Railway, which will run from Fundy to the Gulf of St. Lawrence, a distance of about 17 miles. Sir John Fowler, Mr. B. Baker, and Mr. McKetchom are the engineers, and Mr. J. G. Meigs the contractor. The line is perfectly straight, and is being laid with two pairs of 110 lb. steel rails to a 4-feet 8½-inch gauge, the distance between each pair of rails being 16 feet. The steepest gradient is 1 in 500, and at each end of the line vessels up to 2000 tons will be raised 40 feet on 16-wheeled trucks, resting upon hydraulic lifts. This line will form a tribute to the memory of the late Mr. James B. Eads, to whom is due the credit of having conceived and worked out a practical design for a ship railway between the Atlantic and the Pacific Oceans. The route was over the Mexican Isthmus, from the Gulf of Mexico on the Atlantic side to Boca Barra on the Pacific side, and the total length was about 134 miles. Mr. Eads first propounded this scheme in this country, at the jubilee meeting of the British Association at York in 1881, and from that time up to the date of his death, which occurred on March 8th, 1887, he devoted his best energies to the development of the enterprise.

The chief railway incident of note in our own country during the past year was the sensational race in August between the companies running from London to Scotland on the eastern and western routes. After a spirited contest, in which the time occupied by the journey was reduced from nine hours by one route, and ten hours by another, to a normal—perhaps, to be correct, I should say abnormal—eight hours by both, a compact was made between the two companies, under which the mimimum time was fixed for both at eight and a-half hours, During the contest the run was twice performed by the east coast lines in seven hours and a-half. It was not quite clear what either company could gain directly by performing the journey in such breathless haste, and certainly at some risk. But the impression was that the rivalry was merely an antici-

pation of the conflict which will in all probability arise when the Forth Bridge is opened. This impression is strengthened by the circumstance that some new locomotives of increased weight and power are being built at Crewe by the London and North-Western Railway Company, with the view of working the Scotch express traffic, it having been found that the running made during the contest put a great strain upon the present express engines. The new engines are to be about 20 tons heavier than the old ones, and are designed to withstand the strain of high speed, and to have increased drawing power. The surmise last year that the contest is merely a preliminary skirmish, in anticipation of a more serious battle between the two companies and their allies over the whole of their systems, and from the south of Great Britain to the north, is not unreasonable. At present, all the direct traffic between the north and south of Scotland necessarily passes through Stirling, and over the lines of the Caledonian company. When the Forth Bridge is opened, the North British company will have an independent line, with through traffic to Perth and Dundee, as well as to Aberdeen and Inverness.

The allusion I have just made to that greatest engineering feat of modern times—the Forth Bridge—suggests a reference to the progress of that structure. With its description every one has long been familiar, so that I need not repeat it here. This splendid work, of which Sir John Fowler and Mr. Benjamin Baker have the engineering responsibility, made great progress last year, the progress being very noticeable to those who may have seen it in the previous year. Its actual progress is best gathered from the last quarterly report of the Government inspectors, Major-General Hutchinson, R.E., and Major Marindin, R.E., which report was published at the commencement of the present year. According to that document it appears that at South Queensferry nearly the whole of the principal members of the second bay of the south cantilever are completed, and the bottom members of the third bay, with three-fourths of their bracing, are built out to the commencement of the junctions with the fourth bay. The work done on the north cantilever is rather more advanced than that on the south. The rivetted work at South Queensferry now amounts to about 10,600 tons, an addition of about 1,830 tons during the quarter, as compared with 1,545 tons during the previous quarter. At Inchgarvie, in the south cantilever, with the exception of a small portion of the struts, with their bracings, and a portion of the internal viaduct, the whole of the first bay

is completely built and rivetted. Nearly the whole of the second bay is complete.

In the north cantilever, the work executed on the first bay is almost identical with that on the south cantilever. Practically, the whole of the second bay is in place, and nearly one-half is rivetted. Considerable progress has also been made with the third bay in each case. The total amount of rivetted steel work at Inchgarvie is about 12,400 tons, an addition of about 2,400 tons during the quarter, as compared with 1,630 tons during the previous quarter. At North Queensferry, nearly the whole of the second bay of the south cantilever is erected, and more than two-thirds rivetted. The only portions remaining to be executed are one length of flange plates on the top members, and the flooring and wind fence of the internal viaduct. The bottom members of the third bay, with one-half of their bracing, are built as far as the junctions with bay four, and the greater portion of the junctions is in place. The second bay of the north cantilever is advanced fully as far as that of the south cantilever. The bottom members of the third bay, with one-half of their bracing, are built for a distance of 435 feet from the vertical columns, and rivetted for about 350 feet. The total quantity of rivetted steel work at North Queensferry amounts to about 11,000 tons—an addition of about 2,170 tons during the previous quarter. On the whole bridge, up to the present date, about 614,000 cubic feet of granite have been delivered, 610,100 cubic feet have been set, and about 113,250 cubic yards of rubble masonry and concrete work have been built. In all 53,680 tons of steel have been delivered—an addition of 1,150 tons during the quarter, as compared with 1,210 tons during the previous quarter.

Although not comparable with the Forth Bridge as a whole, yet the bridge over the Rohri Pass of the Indus at Sukkur ranks second to it as regards span. It is to be opened next month, and until the Forth Bridge is completed, the Sukkur Bridge will rank as the largest span bridge in the world. This bridge is on the cantilever principle similarly to the Forth Bridge, and was designed by Sir A. M. Rendel, and forms the connection between the railways for Karachi and Quetta on the one side, and the line to Lahore and Delhi on the other. It also affords direct communication with the Bolan Pass and Candahar, and will thus form an important link in the chain of frontier lines now in the course of construction. It is of one span only, but that span is 790 feet in the clear between the

abutments, and 820 feet between the vertical columns. There is a space of 200 feet between the ends of the two cantilevers, which is filled in by a girder. The main guys which hold back the whole of the structure, are 302 feet long, and are connected to anchors formed of steel plates, built in masonry below the surface of the ground at each end of the bridge. The superstructure includes raking pillars 174 feet long, which incline towards a point 169 feet high, where they meet the guys. There are also a series of struts inclining at an angle of 35 degrees towards the centre of the bridge, and also inwards, these struts being 210 feet long and 16 feet square at the centre. The rail platform consists of two horizontal girders running from end to end, placed 18 feet apart, and having cross girders every 8 feet. The bridge is constructed of steel, there being 3,200 tons of that metal in the cantilevers, and 257 tons in the connecting central girder. The bridge was manufactured at the works of my firm, and it is with pleasure that I call to mind the visits made by the members of the Society during the temporary erection of the cantilevers there in 1885 and 1886. The timber staging used in the erection was 400 feet long by 120 feet wide and 180 feet high, and absorbed 2,400 loads of timber and some 40 tons of bolts and nuts. This structure, which for a long time formed a prominent object on the bank of the Thames at the Isle of Dogs, has now disappeared from view.

In conclusion, I would briefly call your attention to the circumstance that, notwithstanding the announced opposition of the Government, the Channel Tunnel Company intend proceeding with their Bill before Parliament. The promoters state as a reasons that since last year they have received great encouragement from some of the manufacturing and commercial centres of England and Scotland, as well as promises of support from Members of Parliament. The machinery used for boring the tunnel is still in the heading, and is occasionally put in motion to keep it in working order, but no attempt is made to advance the heading, which is about 2,100 yards long. The boring operations near the mouth of the tunnel are, however, still continued, a depth of about 1,000 feet having been obtained. The character of the strata is said to be such as to encourage the hope that coal will ultimately be reached. The boring for coal should by all means be encouraged, but the tunnel work should not be, for in the present state of public opinion, the money spent in that direction will only be

money wasted. This may also be said of any money invested in the tunnel as a commercial speculation, which, if not money wasted, will, I fear, be money lost.

I can only thank you, gentlemen, for the kind hearing you have given to the few remarks I had to lay before you, and I trust that this Society will have a prosperous and a progressive year.

March 4th, 1889.

JONATHAN R. BAILLIE, PRESIDENT, IN THE CHAIR.

THE CONSTRUCTION AND REPAIR OF ROADS.

BY GEO. R. STRACHAN, ASSOC. M. INST. C.E.

IN venturing to address this Society on the science of road making, the author feels constrained to observe that he is fully aware, by criticism to which he has been subjected, as well as by reading, that the persons of all others who are least acquainted with the laws which govern this class of work are surveyors to local authorities; and that the man who rides on a cart, the boy who pushes a truck, and still more especially the person who mounts a cycle, are better qualified by training and experience to determine the issues raised. The only claim the writer has for a hearing is that, among other things, he is a maker of roads, and that his object is to submit to the meeting views which are based upon the results of practical experience. The literature on the subject is voluminous and for the most part useless, and its perusal might lead to the inference that when a man has nothing else to do he writes a pamphlet abusing roads and road-makers, at the same time pointing out the real principles upon which, in his opinion, the science stands. As curiosities of the literature of bygone days upon the subject, reference may be made to the following extracts from works in one of our national libraries, viz. Robert Phillips, in 1737, thus wrote:—"Roads may be considered as made up of three sorts of matter; first, stones as big as eggs and less; second, a yielding substance such as mould, clay, or loam; and third, water." He further says, "Water may be had from the New River pipes at a small expense sufficient to mend Islington Road; from Chelsea pipes as they go across at Knightsbridge to mend Kensington Road." Water may have played a part in the structure of roads, and also as a mender of roads, in the past, at a time when water could be obtained from a water company at a small expense, but the conditions of to-day are entirely different. R. R. Bramley, writing in 1805, avoids meagre details and plunges at once into

the eternal principles of the question, commencing thus, in his 'Road Maker's Guide.' "The first principle apparently impressed by Almighty power upon all inert matter is a tendency to become proper for the system of vegetation . . . . from this cause it becomes the proper study of the road-maker to select such materials for that use as are most distant from the capacity of supporting vegetables."

The portion of the subject proposed to be considered by the author is confined to carriageways which have town traffic upon them, and only incidentally touches on footways. The detail involved in discussing the whole range of roads from country lanes to first-class pavements would be so great as to obscure the issues; the writer therefore confines his observations to roads of heavy traffic, and trusts that the principles on which he relies may be made clear in this limitation of the subject. In giving figures as to the cost of roads, he would wish to say that they apply to Chelsea for the most part, and are not intended to be taken as being universal; but in order to make the paper as useful as possible, he has placed the quantities and prices on which they are based, at the end, so that the task of determining the costs in different places may be attained by adapting the prices to local conditions. As the methods used for ascertaining traffic weights are various, that adopted in Chelsea is described below. It is not claimed that the result given is strictly accurate, for strict accuracy is not to be attained in traffic weights, but as it is adopted in every case its comparative value is reliable.

Traffic returns for Harrow Road (in Chelsea), on 14th December, 1885, from 6 a.m. to 6 p.m.:—

173 omnibuses	at 2 tons each	=	346 tons.
117 cabs	$\frac{5}{12}$ „	=	49 „
368 carts	2 „	=	736 „
717 waggons	$2\frac{1}{2}$ „	=	1793 „
110 other vehicles	$\frac{1}{2}$ „	=	55 „
Traffic weight in 12 hours		=	2979 „
„ 16 „		=	3972 „

Width of road = 11 yards . ·. traffic weight per yard of width in 16 hours = $\frac{3972}{11}$ = 361 tons.

Macadam Roads.

It is impossible to discuss the construction of roads without subjecting the practice of McAdam to criticism. The prevalent idea appears to be that wherever modern road-makers differ in

their practice from that followed by McAdam, they are in the wrong. The writer is among those who, while honouring the name of so great a man, ventures to say that he laid down varying statements on the subject, carried his deductions further than facts warranted, and that his system has well-defined limits within which only it is applicable. Fig. 1 shows McAdam's practice, based on twenty years' observation. The stones were to be laid to a depth of twelve inches on the natural bottom, each stone was not to be above one inch in any of its dimensions, and the shape was to be as flat as possible "if it is not hollow in the middle it is sufficient: the less it is rounded the better: water cannot stand upon a level surface." His later practice is shown in Fig. 2; the depth of the stones was reduced to ten inches, their size was increased to the weight of six ounces (practically a two-inch Guernsey granite stone), and a crown of three inches was given to the road when it was thirty feet wide. It is curious to notice how McAdam held to his method of weighing stone rather than measuring it. He made his surveyors carry a pair of scales and a six-ounce weight in their pocket by which the stones were to be judged, and he was "confident there is little difference in appearance and none in effect" with stones of different material selected by these means. It is thus seen that at one period he declared that "every piece of stone put into a road which exceeds an inch in any of its dimensions is mischievous," and at a later period advocated an increase in the size to what is practically a two-inch stone, having eight times the capacity of the one-inch stone. McAdam further considered his system of road-making as universally applicable, and hence he wrote "the advantages of good roads when compared with pavements are universally acknowledged; the extension of pavement is therefore to be deprecated as an actual evil, besides the greatness of the expense." There are three points on which modern road-makers differ from McAdam's practice:—(1) In the use of binding material when the stones are laid; (2) In the use of a constructed foundation to a road; and (3) In laying pavements; and each of these points deserves consideration.

(1) *The use of binding material at the time the stones are laid.*—The popular idea of a macadam road is that the stones unite and hold together by their angles, without any binding material, and that it is therefore like a sieve through which water would run freely. This view does not receive any countenance from McAdam, as the following extract shows:—"It is the native soil which really supports the weight of traffic; while it is preserved in a dry state it will carry any weight without sinking, and it does in fact carry the road and the carriages also: this

native soil must previously be made quite dry, and a covering impenetrable to rain must then be placed over it to preserve it in that dry state; the thickness of a road should only be regulated by the quantity of material necessary to form such impervious covering, and never by any reference to its own power of carrying weight." How, then, do the loose stones in a macadam road get formed into an impervious covering? The answer is, by the dirt that works up, and the wear and waste of the stones themselves as they rub against each other when vehicles pass over them. When a macadam road is consolidated, the stones are held together with a binding material formed by their own waste, and until they are so held together, the road is not made. Modern road-makers add a binding material at the time the stones are laid, and they claim for their practice that it is less wasteful of stone, more humane than allowing animals to grind a binding material from the stones, and allows the public the use of the road sooner than McAdam's method. In principle there is no quarrel between McAdam and modern road-makers, as both regard a binding material to be a necessary part of the road; their difference consists solely as to the manner of, and time for supplying it.

(2) *The use of a constructed foundation.*—In the extract given above from McAdam's writings, the native soil is stated to be the foundation of the road, and the stone covering acts as a wearing surface and an impervious covering to the foundation. This method of construction is open to objection on three points, viz.:—(*a*) The stones act as a means of distributing the weight of the vehicle over an enlarged area of the native soil, but as they possess no carrying power beyond that gained by their adhesion to each other, it is obvious that a greater depth will be required to distribute the weight than would be necessary to distribute it if a weight-carrying foundation was interposed between the wearing surface and the native soil. Fig. 3 shows how the weight of the vehicle is distributed on the native soil in a macadam road. Fig. 4 shows a Telford road with its carefully constructed foundation of stone punning set by hand labour, and its wearing surface of broken stone. The wearing surface distributes the weight to the constructed foundation, which again distributes it over the whole of the native soil bottom, and thus secures equal results in carrying capacity at a less expenditure of material. As a scientific result, the Telford road is a superior construction. (*b*) The cost involved in laying the whole depth of the road with the material used as the wearing surface is unnecessary. An inferior stone or substance will serve the purpose of a weight distributor at a less cost than the wearing surface stone. (*c*) It

is not advisable to put 2-inch broken stones of a hard nature on native soil, because the weight passing over them drives them into it.

(3) *Laying pavements.*—McAdam claimed that his roads were superior to pavements, and he declared the extension of the latter to be an "actual evil." Modern road-makers say that after a certain limit of traffic weight is reached, macadam roads are noisy, dirty, wasteful, and expensive; and they claim that the pavements they lay give more comfort to the user, less hardship to the animal, and greater convenience to the public. The action of traffic on a road is a mixed one. The feet of the horses strike it a succession of blows in coming down, and in rising they tend to tear the surface. The vehicles cause an abrasion of the surface stones, and exert a pressure through the yielding substances until the weight-carrying foundation is reached and the wheels also strike the road heavy blows as they bound along. A macadam road is a mass of inferior concrete, made of hard small stones and a plastic binding material of dirt. The blows of the traffic disturb the surface stones by driving them down, and thus the stones in the interior are displaced. The tearing and abrasion of the surface moves the stones in their beds of dirt. The combined influence of the traffic actions is to keep the mass in a state of movement, and to cause internal as well as external wear. In country roads where the traffic keeps in one track, only turning to the side to allow other vehicles to pass, the surface wear and internal displacement take the form of ruts. In towns where the rule of the road is observed the surface wear and internal displacement take the form of shallow depressions, which grow in the direction of the traffic. These defects are inherent in macadam roads, and are not the fault of the road-maker, and they prove that, in heavy traffic, macadam roads are an unsuitable structure.

The author, therefore, submits that in the points on which modern road-makers depart from McAdam's rules, they have sound grounds for doing so.

In proceeding to discuss the practice of to-day in making roads, it will save misunderstanding if the term macadam road is applied to any road which has a wearing surface of broken stone, whether the stone is granite, flint, or gravel, or in fact whatever the stone may be. The principle which guides the author in constructing macadam roads is to place a foundation of material (of greater hardness than the natural soil, and of less hardness than the wearing surface) between the natural soil and the wearing surface. The nature of that material may vary in each district according to circumstances. If stone quarries are close at hand, it may be economical to construct a

Telford foundation. In London, where stone is expensive, good brick rubbish or hard clean clinkers make a serviceable and economical bottom. Fig. 5 shows the section used by the author for a 40-foot road in Chelsea for residential traffic.

The natural bottom is shaped to the finished curve of the road, and upon it 12 inches of hard core is placed. The hard core is rolled with a steam roller until it is thoroughly consolidated and of the proper shape. A coating of broken granite, $2\frac{1}{4}$ inch gauge, is then spread over it to a finished thickness of 4 inches, and is rolled dry. Binding material, known as hoggin (a loamy soil), is then swept over the granite in a liquid state while the roller is at work, and by this means the interstices between the stones are filled. Three days are allowed for drying, and then the road is opened for traffic. The cross section of the road is a segment of a circle rising in the centre three-eighths of an inch for every foot of the half width. The width of each path is one-sixth of the total width of the road, thus setting apart one-third for foot traffic and two-thirds for vehicular traffic. The least fall given to the channel is 1 inch in 10 feet. Such a road 40 feet wide costs per yard run as follows, viz. :—

	£	s.	d.
Footway	1	6	6
Kerb	0	10	6
Channel and gulleys	0	18	0
Carriageway	1	10	0
Total per yard run	£4	5	0

The macadam carriageway costs 3*s.* 10½*d.* per square yard. If the wearing surface were made with flints instead of granite, the cost per square yard would be 3*s.* 2*d.*, and the cost per yard run 4*l.* Details are given in Schedule A.

The section used for roads of heavy business traffic is shown in Fig. 6. The foundation of hard core is 18 inches deep, and after it is thoroughly rolled, three inches of gravel is spread over it, and this is rolled in the same manner, and then the wearing surface of broken granite is spread to a finished thickness of 4 inches and finished off as in the road shown in Fig. 5. The cost of a road 40 feet wide, as per Fig. 6, per yard run, is

	£	s.	d.
Footway	1	6	6
Kerb, 12 in. by 8 in.	0	10	6
Granite channel and gulleys	0	18	0
Carriageway complete	2	0	0
Total per yard run	£4	15	0

The macadam carriage-way costs 5*s.* per square yard.

The stone used for the wearing surface of macadam roads should be determined by local conditions, but the choice of it should be made on strictly commercial principles. If a high-priced stone from a distance gives superior results to a lower priced local one, the former should be used. In the metropolis broken granite is used in almost every case for roads of heavy traffic. Flints are used to a large extent in those streets where traffic is purely residential, and in some cases gravel is used. Flints are cheerful in appearance, pleasant to travel over, and comparatively noiseless, but they are dusty in dry weather, and will not bear much traffic. The writer uses broken granite of a $2\frac{1}{4}$-inch gauge, and finds that with stones of that size the road is easy to travel on, and at the same time, the stones are of sufficient size and bulk to give solidity and body to the road. The binding material used is the before-mentioned hoggin. An experiment was made with two adjacent sections of road, on which the traffic of necessity was the same, by using small granite chippings as the binding material in one, and hoggin in the other; and the result showed that granite chippings are unsuitable for such a purpose. A very interesting opportunity for observation is afforded by the Chelsea Embankment, where a foundation of concrete 12 inches in thickness is placed under the carriage-way to prevent subsidences, but so far as the writer can determine, such a foundation does not add to the life of the wearing surface.

The method of repairing followed in Chelsea is as follows:— The surface to be repaired is picked up by scoring it to a depth of three inches, so as to thoroughly loosen all the surface stones. The stones are then regulated to a proper curve and new stones added. The steam roller is then used to bed the old and new stones, and after they have found their place, liquid hoggin is added when the roller is at work. The steam roller (10 tons or $12\frac{1}{2}$ tons weight) rolls 300 yards per day of 10 hours, when the thickness of new stone added does not exceed 2 inches. The cost of repairing a macadam road in this manner with 2 inches of broken granite is about one shilling per square yard. In Schedule B is given the details of the repair of a macadam road. The author has endeavoured to discover a formula to determine the amount of wear on macadam roads according to the traffic weight, and also the cost, but has failed. The ratio of cost and wear to traffic weight is very much more than a direct one, and where the traffic is beyond 300 tons per yard in width per day, the ratio of cost and wear increases as the square of the traffic weight, at least. When Piccadilly was a macadam road, the annual cost of maintaining it was 4*s.* per square yard per annum, or, to put the result in

another form, the cost of maintaining a similar road 36 feet wide would have been 4224*l.* per mile per annum. This fact tends to prove that the limits within which macadam roads are suitable for heavy traffic are soon reached.

Paved Roads.

As regards these, and before discussing their capabilities, the author wishes to enunciate the principle he follows in constructing roads generally, viz. that the real road is the foundation which carries the traffic, and the material on the foundation over which the traffic passes is only a wearing surface. Thus, in a paved road with a concrete foundation, he regards the concrete as the actual road, and the asphalte, wood, or stones paved on it as the wearing surface. This principle secures economy in construction, for in making the foundation the point to be secured is a rigid, weight-carrying body, which need not necessarily be capable of resisting in itself the complex mechanical and chemical actions which a wearing surface has to endure; and on the other hand, in making the wearing surface a body capable of resisting the climatic changes to which it is subject, the chemical actions of the air, rain, filth, and dirt which come in contact with it, and the mechanical strains of pressure, compression, abrasion, and tearing caused by the traffic, without considering whether in itself it is a weight-carrying body. It also secures economy in maintenance; for when the wearing surface is worn out, the real road is as good as before, and when the wearing surface is renewed, the road has a new life practically equal to its original life.

The author regards it as the duty of the road-maker, to make roads suited to the traffic, as opposed to the idea of suiting the traffic to the road. He regards all legislation regulating width of wheels, &c., as mischievous and useless. In McAdam's day, cart wheels which were wider than 6 inches were not taxed. The cart owners got the benefit of the exemption by making broad wheels with a conical tyre, and in one instance by making the wheels 16 inches wide and fixing a 3-inch tyre in the centre, the result being that the wear on the roads was the same as that caused by narrow tyres. If the public wishes roads to be capable of carrying omnibus traffic, and at the same time to be cycle tracks, the writer regards it as the duty of the road-maker to realise the wish, and of the ratepayer to find the money without grumbling.

Concrete foundations.—In order to illustrate the method of constructing the real road or the foundation, adopted by the author, the common case of converting a macadam road into a

paved road may be instanced. The first work is to excavate the macadam so as to shape the bottom, and this is done by driving steel wedges into the crust by blows from sledge hammers. When a small portion has been removed, the wedges are driven under the crust and lifted by long levers, thus raising from 20 to 30 square feet at a time. A few blows from heavy hammers disintegrates the mass, and it is then easily moved with pick and shovel. The macadam is then screened through a one-inch sieve, and the stones left on the sieve are carted away for use on other roads. At one time the writer screened the residue through a half-inch sieve, but the result was not worth the cost, and he now sends it all away to a shoot as waste. The bottom of the road is then shaped to the finished curve, and the screeds are then fixed. Two-inch pegs are driven alongside the kerb and down the centre of the road at distances not exceeding 6 feet apart. A wood lath 3 inches wide and $\frac{3}{8}$th thick is then nailed on the pegs and carefully bedded on concrete by means of long straight-edges. Twenty-four hours after they are bedded they are ready to be used. The screeds in the centre are the actual finished levels of the crown of the foundation, while those at the channels are the finished levels of the foundation at the channel. The concrete is then placed on the sides of the road and roughly finished off to within half an inch of the finished surface, after which cement grout is placed on it and accurately surfaced by means of templates of the proper shape, one end of which rest on the screed at the channel, and the other end on the screed in the centre, and which are drawn along the screeds in the longitudinal direction of the road. After drying for three or four days, the wooden screeds are taken out, their spaces filled in with a cement grout, by means of a hand mould, and then at the end of seven days from the finishing of the bulk of the foundation, it is dry enough to place the wearing surface on it. The depth of the concrete is 6 inches, and such a thickness carries 600 tons per yard in width per day, without any deterioration. It is made in the proportion of six parts by measure of Thames ballast to one part by measure of Portland cement, and the cement grout is made in the proportion of three parts of Thames sand to one part of Portland cement, by measure. The cement used is the best Portland cement, capable of bearing a tensile strain of 420 lbs. per square inch after seven days' immersion in water, and which gives a less residue than ten per cent. on a sieve with 2,500 holes to the square inch. The writer has learned by experience that it is one thing to have a stringent specification theoretically perfect, and another thing to get the article specified. In order to

obtain the cement of the quality specified, he has it delivered on to the work ten days before it is wanted for use, in 50-ton lots. As each lot is completed it is sampled and sent to Mr. Faija, a member of this Society, for testing, and before the ten days are expired the report is received. If the cement answers the specification, the particular lot from which it was sampled is used; otherwise, the whole lot is rejected. In order to secure the proper proportion of ballast and sand to cement, the writer has special measures made to hold the ballast and sand, which are not half-yard or quarter-yard measures, but which hold respectively the contents of six bags and three bags of the cement as it is delivered on the ground. The ballast and sand are measured but not the cement, for one bagfull is placed with each measurefull. As regards the inclination of the road, the writer carries the crown and the channel at the same rate of inclination where the fall of the road is equal to or more than 1 inch in 15 feet, and in such a case the cross section is a segment of a circle rising $\frac{3}{8}$th of an inch in the centre for each foot of the half width. When the inclination of the road is less than 1 inch in 15 feet, a fall of at least that inclination is given to the channels by taking the channel in opposite directions from a summit between the gulleys. In his practice he places the gulley 7 inches below the kerb level, and the summits 3 inches below, and by raising the crown of the foundation opposite the gulleys, a half-inch for every foot of the half width, and keeping the crown at a regular inclination from point to point opposite the gulleys, he overcomes the difficulty of a varying cross section. The template used to shape the concrete has a $\frac{3}{8}$th rise, and though its use is not mathematically correct, in practice no inconvenience arises. When cross roads are paved, the crowns are kept at regular inclinations and the haunches are shaped accordingly. In Schedule B the method of making the template is described and a mathematical demonstration of its accuracy is shown. When a foundation is made as described, there is no limit to its life, except that imposed by the ravages of the natural enemies to good roads, viz.: gas, water, electric light, and other companies, when they tear it up to get at their mains and pipes.

In coming to the question of wearing surfaces, the author discusses them in the order of what he regards as their merits.

Asphalte.—He does not hesitate to say that he looks upon a wearing surface of asphalte as the best road of to-day. Its one disadvantage of slipperiness does not in his opinion outweigh its advantages of durability, cleanliness, economy, and healthiness. It gives results as regards wear which are not

approached by any other wearing surface. When laid $2\frac{1}{4}$ inches thick in a compressed state, a life of fifteen years will be obtained from it under the heaviest metropolitan traffic; such for instance as that of Cheapside. The cost of the road, including the concrete foundation is 13*s.* per square yard, and for the first seven years no repairs would be necessary, and the cost of the repairs in the remaining eight years would not exceed one shilling per square yard per annum, or an average during the whole life of the asphalte of sixpence per square yard per annum. The first cost of such a road 36 feet wide would be 12,788*l.* per mile, and the cost of repairs would average 528*l.* per mile per year for a life of fifteen years. At the expiration of fifteen years the asphalte can be renewed at half the first cost, and then the road is equal to another fifteen years' life. Mastic asphalte is not so well suited for carriageways as compressed. Compressed asphalte is the natural rock ground to powder, without admixture, and it can therefore be readily tested by analysis. The writer has described at length the manipulation asphalte undergoes to make it fit for road use, in a paper read at the Leicester meeting of the Association of Municipal and Sanitary Engineers and Surveyors, which is published in the 'Proceedings' of that society for 1886; he, therefore, contents himself with giving the following analysis of reliable asphaltes in this paper.

	Bitumen.	Carbonate of Lime.	Silica, Moisture, &c.
Val de Travers Co.	8·58	88·67	2·75
French Asphalte Co.	14·40	82·50	3·10

Wood.—A wearing surface of wood makes a useful road, possessing the advantages of comparative noiselessness, good life, secure foothold, (except when it is just damp as opposed to being wet), and of reasonable cost. It has, however, an unpleasant odour after it has been wetted, and is difficult to keep in good repair. In King's Road some yellow deal blocks have been down for ten years under a traffic weight of 500 to 600 tons per yard of width daily, and the wear has not equalled 3 inches in any part. The practice of laying wood in Chelsea is as follows:—The blocks are laid directly on the concrete foundation, in transverse courses, with their butt joints in contact, and with a $\frac{3}{8}$th joint between the courses. The joint between the courses is maintained by means of three iron studs driven into the face of each block. The studs keep the joint until the grouting is firmly set, and the author maintains that by their use, the regularity of the joints is greater than by using laths. At junctions with other roads the courses are intersected at an angle of 45°. When the blocks are laid the

joint is made with cement grout (three of sand to one of cement) and after seven days' drying, the surface of the wood is covered with small gravel stones and the traffic turned on to it. The stones are crushed to pieces by the wheels, and are driven into the surface of the wood. A margin is left between the wood blocks and the kerb for the expansion of the wood, and is filled in with clay. The depth of the blocks now used is 5 inches, and yellow deal is the timber selected. The cost of converting a macadam road into a wood-paved road is 9*s.* 6*d.* per square yard; but in this price no credit is taken for the old macadam, channel stones, &c., which are available for use elsewhere. With a traffic weight of 600 tons per yard per day, there will be no cost for repairs for the first three years, and a useful life of eight years will be obtained. The average cost of repairs under such a traffic will be 3*d.* per square yard per annum. The first cost of such a road 36 feet wide would be 9932*l.* per mile, and the average cost of repairing it would be 264*l.* per mile for an eight years' life. In Schedule C, the details of the cost of a wood-paved road are given. On the question of hard and soft woods, the Chelsea experience has been that hard woods, such as beech, &c., give an unpleasant trembling motion to vehicles, the joints widen out, and the surface wears into short deep holes; while the softer woods wear more evenly, and are more pleasant to travel on. The surface size of blocks, 9 inches by 3 inches, is now almost universally adopted. On the question of creosoting wood, the author has no doubt it adds to the life of the wood, and where very heavy traffic exists its use is to be commended. Where plain blocks give an eight years' useful life, it is a matter for consideration whether the additional two years' life, at an increased expense of more than one shilling per square yard, is worth having. It appears to the author that a new wearing surface every eight years is to be preferred to extending the life to ten years when the costs are alike. If wood is creosoted, there should be 16 lbs. of the creosote oil forced into each cubic foot, but the user should select the wood before it is treated, and see the blocks put into the tanks. When creosoted blocks are used, the joint should be made with pitch, for the inch nearest the concrete, and then completed with cement grout. Pitch by itself forms a bad joint, as it does not afford sufficient support to the blocks at the edges, and with plain blocks is unsuitable, as it does not grip them. The author specifies best Swedish yellow deal, and insists on having a sound block, practically free from sap. The surest way of testing blocks is, after wetting them, to leave them in the open for a day or two. If they are then practically free from sap, they may be used with confidence.

When the wood needs renewing, the cost is about 5*s.* per square yard, and the road is then as good as when it was first made. The fact that wood is not a suitable wearing surface where the traffic is under 100 tons per yard in width per day, cannot be too much insisted upon. On such a road the blocks would rot out in a shorter time than they would wear out with six times the traffic. Each district has its own limit of traffic weight at which it pays to convert the macadam into wood, but in Chelsea the limit is 270 tons per yard in width per day; when the traffic reaches that weight, it is cheaper to take up the macadam and lay down wood.

Granite pavements.—In mentioning stone pavements, the writer thinks it well to say at once that he regards the noise caused by them to outweigh all their advantages. For a stone-paved wearing surface, the concrete foundation does not need so carefully finished a top as for asphalte or wood. The stones cannot at a reasonable cost be made sufficiently true in depth, so as to be laid on the concrete and give a true surface: a bed of sand is therefore laid on the concrete, and serves the double purpose of a cushion and a regulator for the unequal depths of the stones. The author prefers the stones 3 inches wide and 7 inches deep when a concrete foundation is laid, and after that 4 inches by 6 inches. Guernsey and Aberdeen granites make very good paving setts. When the joints are made with cement grout, an excellent road is formed: when made with pitch, the joint wears more than the stone. The first cost of a 3-inch by 7-inch Guernsey stone road on a 6-inch concrete foundation would be about 15*s.* per square yard, and the repairs would not exceed 1*d.* per square yard per annum for 15 years' life, with a 600-ton traffic weight per day. The first cost of a roadway so constructed, 36 feet wide, would be 15,840*l.*, and the annual cost for repairs would be 88*l.* Such a road is more economical than one of wood.

The author may say that he regards all attempts to pave roads on natural bottoms as makeshifts, and that he looks upon the efforts to make the wearing surface carry the load as unscientific and wasteful. Roads built on Telford foundations may be useful in country towns, but they are unsuitable for heavy traffic. Having stated his practice and principles at so great a length, the question of the construction of roadways of a minor kind cannot be entered upon, and in closing his paper he trusts that his principles may be carefully criticised and his practice examined and fully discussed.

SCHEDULE A.

COST OF A 40-FOOT MACADAM ROAD, 200 FEET IN LENGTH (*vide* Fig. 5).

			£	s.	d.
Footway—					
Excavation, cart and shoot	30 cube yards	at 3*s.*	4	10	0
1 in. asphalte on 3 in. concrete	267 square yards	at 6*s.* 3*d.*	83	8	9
Kerb—					
Excavation, cart and shoot	17⅓ cube yards	at 3*s.*	2	12	0
P. C. concrete, 6 in. thick	7½ „ „	at 10*s.*	3	15	0
12-in. by 8-in. granite kerb	400 feet run	at 1*s.* 6*d.*	30	0	0
Channel and gulleys—					
Excavation, cart and shoot	20 cube yards	at 3*s.*	3	0	0
P. C. concrete, 6 in. thick	9¼ „ „	at 10*s.*	4	12	6
5-in. by 7-in. granite setts	55½ square yards	at 12*s.*	33	6	0
4 gulleys complete		at 5*l.*	20	0	0
Carriageway—					
Excavation, cart and shoot	232 cube yards	at 3*s.*	34	16	0
Hard core, 12 in. thick	174 „ „	at 1*s.*	8	14	0
Roll hard core	522 square yards	at 2*d.*	4	7	0
Guernsey granite, 4 in. thick, rolled complete	„ „	at 2*s.*	52	4	0
			£285	5	3

SCHEDULE B.

METHOD OF MAKING TEMPLATES. (See Figs. 7, 8, and 9.)

Let A B C D be a board of which the length A B = the whole width of the road. Bisect A B in E. From A set off A F = to the rise of the centre of the road above the sides. Join E F, and saw the portion E A F off, leaving B E F D C. Take a board from which the template is to be cut, H I J K, and mark two points L M on it, so that L M = E F. Fix bradawls in L and M, and then place the side B against L and the point E against M. Draw the board B E F D C to the left, keeping B E against L and E F against M. A pencil held at the point E will trace the half curve of the section, and it will be a true segment of a circle.

Proof.—It is required to show that the angle $hea = \angle hge$.

(1) $\angle hgf = \angle hef$ because they are in the same segment of a circle, $hgef$.

(2) $\angle fhe = \angle fge$ because they are in the same segment, $en..of$.

(3) But $\angle fhe = \angle hfe = \angle fea$ $\therefore$ $\angle fge = fea$.

Now $\angle hge = \angle hgf + \angle fge$,

And $\angle hea = \angle hef + \angle fea$.

Therefore from (1) and (3) $\angle hge = \angle hea$. Q.E.D.

SCHEDULE C.

COST OF WOOD PAVEMENT.

	Per sq. yd.		
Excavate macadam carriageway, screen macadam through 1 in. sieve, cart stones to depôt and refuse to shoot, find shoot, and shape bottom for concrete foundation; total depth 11 in.	0	1	6
Provide and lay 5½ in. of concrete (6 Thames ballast to 1 Portland cement), and cover it with ½ in. of cement grout (3 Thames sand to 1 Portland cement), face off same to finished contour, including screeds, pegs, &c.	0	2	6
Provide and lay 5-in. yellow deal blocks studded and grouted with cement grout	0	5	0
Use of tools and repairs	0	0	4
Testing, water, supervision, &c.	0	0	2
	£0	9	6

DISCUSSION.

On the motion of the President, a vote of thanks to Mr. Strachan for his paper was unanimously passed.

Mr. JOSEPH GORDON said that no doubt there were gentlemen in the room who would be able to corroborate Mr. Strachan's statement that macadam roads were the most expensive with which they had to deal for heavy traffic. The author had instanced the case of Piccadilly, which had cost 4*s.* per square yard per annum to keep in repair. But there were many cases in the suburbs of London, and even in the suburbs of large towns, where the traffic was very limited, and where such roads were very highly prized by the inhabitants. They were not exactly equal to wood in their quality of being silent, but they gave a very pleasant appearance to the locality. No doubt macadam roads would still be made in such districts in which the traffic was light. His experience agreed with that of Mr. Strachan, that macadam roads were exceedingly expensive where there was a heavy traffic, but for some reason the governing authorities looked at the first cost of a road very much more than at the ultimate cost in the way of repairs. If they could get a macadam road for from 2*s.* 9*d.* to 3*s.* 6*d.* per square yard first cost, as they could do in provincial towns, the authorities seemed to lose sight of the annual expense until it was brought before them in some drastic manner, and then macadam roads were frequently converted into paved roads. The great drawback to the latter was that they were too noisy for business streets. The tendency in London was towards silent pavements for which wood as a material was undoubtedly the best. A material which was not mentioned in the paper was the tar macadam; this form of road was not very prevalent in London, but was used to some extent in provincial towns, its life was very much longer than ordinary macadam. It did not cost very much more at first, and very much less to maintain in good order, but it also was unsuited for heavy traffic. For suburban districts it made an exceedingly suitable carriageway, being neat and cleanly in appearance and more silent than any other form of road with the exception perhaps of wood. On the question of the width of roads, no doubt there would be a difference of opinion. The rule given by Mr. Strachan for town roads was to devote two-thirds of the total width to the carriageway and one-third to the two footpaths. In his (Mr. Gordon's) opinion one-third was far too little for the footpaths. He had for a long time adopted the practice of devoting three-fifths to the roadway and the remainder to the footpaths. That was a

proportion which he believed met fairly well the wants of all districts, but where it was proposed to plant trees he added an extra foot beyond the width given by this rule, to each foot-path for all streets 40 feet wide and upwards. He was surprised to hear that Mr. Strachan liked to have a soft intermediary substance between the soil and the wearing surface of a macadam road. The harder the foundation the firmer would be the road when it was rolled with a steam roller. No doubt in London they had to use materials which there was no need to use in provincial towns. As to the size of the metal, he had used $2\frac{1}{4}$ inch metalling for many years, and he found that notwithstanding the binding materials which were used, when a road was rolled with a steam roller the surface wore better when the metalling was of smaller dimensions. The metalling should not exceed a 2-inch gauge. No doubt that for ordinary light traffic $1\frac{3}{4}$ inch would be quite sufficient, and for park roads and drives the metalling need not be larger than $1\frac{1}{2}$ inch. He very much questioned whether Mr. Strachan was right in supposing that the surface of a road ought to be a true segment of a circle. He rather inclined to the formula laid down by Mr. Deacon, the Engineer of Liverpool, who departed from the segment. In many towns a great difficulty arose from there being lopsided, sloping ground to deal with, and a series of horizontal roads ran at right angles to those running in the direction of the slopes. In Newcastle and some other towns, there were roads in which one side was probably from 2 to 3 feet lower than the other. These were difficult cases to deal with, especially at the crossings of other streets or roads; he should have liked the author to have dealt with them in his paper as Mr. Deacon had done, in order to have compared the practices.

As to paved roads, he thought that Mr. Strachan was right in concluding that the disadvantages of them in business thoroughfares far outweighed the advantages of their long life. Ratepayers were, he thought, beginning to be alive to the advantages of a silent pavement in busy streets. Asphalte roads had been thought to be the best sort which could be used, but asphalte roads were very difficult to deal with, especially when the roads were upon sloping ground. It required sanding, and if the sand carts were not sent out very early in the morning, the inhabitants soon complained. Wood pavements were also very difficult to deal with in that respect. He believed that though asphalte roads had many advantages, they would not be the roads of the future, for town purposes. Mr. Strachan thought that hard woods were not to be recommended, and he proposed the soft. It was astonishing how different men came to

different conclusions. In the towns of Newcastle and Sunderland he believed they would have nothing to do with soft woods. In Norwich the whole of the town had been repaved with soft wood, without even the intervention of concrete, and the life of the pavement thus laid down on the natural soil was apparently about as long as with the most carefully prepared concrete foundation. Probably the case of Norwich was not so well known as it deserved to be. He must confess that he was rather surprised to find that Mr. Strachan had given so much as eight years as the life of wood paving. He thought that that duration would scarcely be borne out by the meeting as far as London was concerned. Possibly, wood paving would wear for three years without repair, even under heavy traffic, as Mr. Strachan had stated, but he (Mr. Gordon) was not prepared to hear that it would last five years longer after being repaired. Wood pavement had been laid down by him in Leicester for four and a half years, but it did not look as if it would last three and a half years longer, or even another summer.

Mr. W. Santo Crimp said that it was impossible not to be struck with the excellent way in which Mr. Strachan not only made his roads but maintained them after they were made. He (Mr. Crimp) quite agreed with the remarks of the author on the literature of the subject. They were sometimes treated with a dissertation on road making by an amateur who went over some miles of road on a bicycle, and then wrote a paper on roads. With regard to binding material, he was quite sure that it was good policy to use it on macadam roads where steam rollers were used. In McAdam's day such rollers were unknown, and McAdam trusted to the traffic to consolidate the granite. If binding material was applied to the granite before the road was somewhat consolidated, of course it ran through and was lost. He thought the tendency nowadays was to reduce the size of the stone. He had been using 2-inch stone, but it was his intention during the coming season to specify 1¾-inch. He thought that that would be quite large enough for suburban traffic. He agreed to a certain extent that the roads should be made to suit the vehicles and not the vehicles to suit the roads, but on the other hand those persons who had charge of hilly districts knew how destructive narrow wheels were in such places, and what the result was of a van of two tons or two and a half tons coming down an incline with a 2½-inch chained wheel or narrow skid. He thought that either some limit should be put upon the narrowness of wheels, or that vehicles should be compelled to carry a 4½ or 5-inch skid. As to cement, he was sure that Mr. Strachan had not insisted upon a too stringent specification. Taking into account the large

quantity of useless material which was present in the coarse cement, it was cheaper to buy the finer ground qualities. A smaller proportion of the latter was required in order to make a good concrete. As to the question of creosoting wood blocks, he was not quite sure that he agreed with it. The surveyors ought to see the wood blocks before they were laid, and the way not to see the quality of them was to have them creosoted. He should have been very glad if Mr. Strachan had given the Society some idea as to the limits of the gradients upon which he would use the various kinds of paving materials. With regard to the section in figure 5, he agreed with Mr. Gordon that a better rule would be to make the roadway 24 feet in width and the path 8 feet. Two persons walking abreast require 2 feet each, and an 8-foot path enabled them to pass comfortably two persons walking abreast in the opposite direction. In making a roadway it was very advantageous to consider the width of a vehicle, and to make the multiple of the width of the vehicle the guiding principle, 8 feet was a very convenient width for a vehicle; three times that, or 24 feet, would be an exceedingly good width for a carriageway.

In the details given in the paper with regard to maintenance of various kinds of roadways, no allusion was made to the capital outlay, the interest on which, say at 4 per cent., should be added to annual charge for maintenance, the true relative costs per annum would then be somewhat modified.

Mr. J. P. Norrington said that he considered the paper to be a very interesting and useful one. He had at present a contract in hand for paving the Lillie Road with wood, the specification for which provided that a certain amount of bitumen should be run in between the blocks. He had adopted this plan because he wished to shorten the time during which the road would be closed against traffic. The cost came to 8*s.* 8*d.* per square yard. He thought that was a useful figure for the members of the Society to know. Mr. Strachan had given 9*s.* 6*d.* as the cost for wood-paving. In 1887 he superintended a contract for wood-paving in the King's Road, which cost 7*s.* 7*d.* a yard super; and the North End Road contract, just finished, came to 7*s.* 4*d.* per yard super; both contracts were for plain deal blocks on 6-inch concrete, grouted in cement.

He rather agreed with the remarks of Mr. Santo Crimp about using blocks which had not been creosoted. Ever since he had started wood-paving, the contractors had suggested creosoting, and he could not help being suspicious, and had avoided the employment of the process, especially as, when the plain blocks come on the ground, he had had to reject several thousands, amounting in one case to 12 per cent.

Like Mr. Crimp, he should have liked to have heard something said about the gradients upon which it was safe to use wood. He was now laying the approach to the Lillie Bridge with wood (the gradient is 1 in 25), and was a little nervous as to whether the gradient would not be too steep, even when the pavement was well sanded. There was a point in the London traffic when it became too heavy for a macadam road, and wood became cheaper than macadam. He was able to prove this to his Vestry last year, in the case of Lillie Road, and he estimated that at least 150*l.* a year would be saved by paving this road with wood. In consequence of skidding the narrow wheels of omnibuses, this road used to get so ploughed up that it was impossible to keep it in a decent state of repair. As to the width of footpaths, his experience in Birmingham was with 8 feet footways, and upon coming to London he was very much surprised to find the width to be only 7 feet. He had concluded that the selection of this width was due to the action of the Metropolitan Board, and would suggest that some person should send in a plan for a road with 8-feet footpaths, in order to see what action the Metropolitan Board would take in the matter. Perhaps the new County Council would approve of 8-feet footways.

His practice with reference to the construction of roads had been much the same as that which was represented in the diagrams. He did not attach much importance as to whether the cross section of a macadam roadway 26 feet wide was parabolic or circular.

In reference to the remarks of Mr. Nursey, he would state that he had two sand-distributors in use at Fulham, constructed upon the principle described by him. They are known as Willacy's patent sand-distributor, and worked very satisfactorily.

Mr. J. P. Barber said that it had struck him that the price mentioned in the paper as the cost of hard core, viz. 1*s.* per cubic yard, was very low. At Islington they had to pay 2*s.* per cubic yard delivered. He thought that Mr. Strachan was quite within the mark in giving the life of yellow deal paving as eight years, even upon a road with a fair amount of traffic. He had in his mind the case of some wood pavement in St. George's, Hanover Square, which had lasted for that time, although the streets in which it was laid were not wide ones. Where the traffic was lighter, wood pavement might last even for ten years. 3*d.* per yard super seemed a very low sum for the annual cost of maintenance. His experience was that it was at the very least 5¾*d.* to 6*d.* He should like to have had Mr. Strachan's experience as to the Jarrah wood which was just now being

introduced to this country, as Mr. Strachan was the only surveyor in London who had got a sample of this wood laid. He understood that Jarrah wood was used at Melbourne, in Collins Street and some of the other streets, where there were tramways, with a heavy and rapid traffic and rather steep gradients, and that it answered very well. It was hard and not slippery, and comparatively impervious to moisture, and the blocks near the tram lines did not show any more wear than the others. The Jarrah blocks being comparatively non-absorbent, dried very rapidly after a fall of rain. The firm that imported it said that blocks of 4 inches in depth were quite deep enough for paving, and that it would last three times as long as yellow deal. Assuming its life to be only 15 years, or scarcely twice that of yellow deal, he calculated that the average annual cost per yard super for maintenance would be the same for each material, but there was the advantage of not having the road disturbed so frequently for repairs by using the more durable material. It therefore appeared to him that this material was worthy of notice. Mr. Strachan had given the life of granite pitching as 15 years. That was about half the life which he (Mr. Barber) found it to possess. He had found that the pitching, in a rather narrow road in his district, over which an enormous traffic passed, had a life of 30 years, and the average annual cost of the repairs was $2\frac{5}{6}d.$ per yard super. There were other pitched roads, in the same district, which had been laid over eight years, upon which nothing had yet been spent in repairs, yet they were in a good condition, and would in all probability last more than 30 years with repairs. The author had said very little about the northern system of grouting the granite sets. In the north they were grouted with a mixture of pitch and tar, but very little of this kind of work was done in London. He believed that occasionally the grouting done in London was with bitumen obtained from the asphalte companies, but that, of course, made the process very expensive. He did not agree with Mr. Strachan that flint roads were dirty in dry weather. They were, however, exceedingly dusty, and as the dust consisted of finely ground particles of flint, it was very sharp and caused pain when blown against the face. Flint roads became very soft and dirty during a continuance of wet weather, and in the winter-time, after a thaw, he had found some of them completely disintegrated and lifted up to such an extent as to look exactly like a ploughed field, but after a quantity of rain had fallen they sank down and became consolidated again. As to the size of the broken granite, he had used 2-inch and $2\frac{1}{2}$-inch for repairing, and he must say that he preferred the larger size for heavy traffic. He had some severe inclines in Islington, but

instead of repairing these with broken granite, he used Kentish rag. This became exceedingly muddy and dirty in wet weather, but it seemed to bind together like concrete. He never found it to be ploughed up by the skids or locked wheels, but it was about the last stone he should use on level ground. As to the width of the footpaths, perhaps the explanation of the width of 7 feet being adopted in London was, that when there was a lamp-post near the curb, a width of about 6 feet was left, which allowed room for three people to pass; while if the path was 8 feet wide, the clear space by the lamp-post, although it would be a foot wider—namely, 7 feet, would not allow more than three people to pass, and there would be a space of one foot which would be of no service.

Mr. E. R. SHIPTON said that he was one of that despised class of cyclists to whom one of the speakers had referred in perhaps somewhat contemptuous tones. He was prepared to admit that many cyclists theorised upon roads without much practical knowledge, but they had at any rate a pretty good idea of what was a good surface and what was not. Perhaps they frequently judged roads entirely from their own standpoint, and did not take into account the disadvantages which would follow if all roads were laid down upon the principles which they enunciated. But still he contended that only a cyclist could appreciate to the full a good surface. Speaking as a cyclist, he was pleased to observe the very great strides which had been made by road-makers. They were beginning to believe that a good wood pavement could be recommended, even on the ground of economy, to say nothing of efficiency. He should have liked to have heard in the paper a reference to some better method of sanding the streets. It had been a wonder to him that nothing had been invented for the purpose. As to the size of the granite in a macadam road it had been for a long time the belief of the Roads Improvement Association, to which he belonged, that anything above 2 inches was a mistake. He understood that Mr. Thomas Codrington, a well-known authority, was an advocate for the $2\frac{1}{4}$-inch gauge, when a steam roller was to be employed, but $2\frac{1}{4}$ inches was the maximum that even this gentleman recommended. The Road Improvement Association recognised the fact that the system to be followed in cities must necessarily differ from that which was suitable for country districts where one has to trust to the local traffic for the consolidation of the new coating. They also discriminated between the wisdom of which city surveyors were possessed and the ignorance characteristic of country way-wardens. The efforts of the Roads Improvement Association had been directed chiefly to the end that the

country road surveyor, should be taught to do his work more efficiently, and he hoped it might claim to have brought about an improved condition of things in many districts.

Mr. Perry F. Nursey said that he was not surprised to hear the author of the paper speak in favour of asphalte paving. That pavement was doubtless very dangerous when it had only a slight amount of moisture upon it; but when it was either thoroughly dry or thoroughly wet it was perfectly safe. What appeared to him to be wanting was some foothold for the horses, or some roughness of the surface which would prevent its slipperiness. He met with that feature in the year 1885 when he inspected a process invented by a Mr. Bryant for making a product called grano-metallic stone. This substance was composed of crushed blast-furnace slag and crushed granite which were mixed together in powder and treated chemically. When the mixture was dry it was combined with Portland cement in certain proportions. This powder was then mixed with water and laid down in a plastic condition. The sample which he examined was in front of the Gaiety Theatre, and it was still there. The great point in this composition seemed to be that it gave a very excellent foothold in all conditions of weather. It had been laid down in some provincial towns, but he had not heard that it had made very great progress in London. The great value of grano-metallic stone lay in the circumstance that the ingredients possessed different degrees of hardness. The most refractory was the slag, the sharp, vitreous particles of which wore down less rapidly than other associated materials, and always presented themselves just above the surface of the mass, thus insuring a good foothold at all times. He had met with a stone obtained from the Belan quarries in the Breidden mountain range, and which was much used in Shrewsbury. It formed a very excellent non-slipping roadway. The stone was a very hard greenstone and some of its constituents presented minute hard points. It was of that stone that Telford made the Holyhead road. He was told that the difficulty of getting that stone introduced into London instead of granite pitching, was vested interests. As to the sanding of roads, some very convenient methods had been invented for that purpose. He did not allude to those sand-distributing carts which travelled along and merely left a train of sand behind them. He referred to a cart invented by Willacy, of Preston, and which was suitable for distributing sand, manure, and water. It had two revolving discs overlapping each other in the tail of the machine. These discs were grooved radially, and as the sand, water, or manure fell upon them they distributed the material right and left over

the roadway, covering a very wide area. This cart had been to some extent improved upon recently by Mr. Strawson. The principle was the same as in Willacy's, but the machine was more effective and even in its distribution. But apart from the use of sand distributors, they ought to observe the fundamental principle of making roads which should in themselves be free from slipperiness.

Mr. C. H. Lowe said that his district at Hampstead was composed chiefly of macadamised roads. Possibly, one mile of the forty miles was non-macadamised. He agreed with the author as to the cost of forming new roads. He found the best width for a footpath was 8 feet, laid out as follows, viz.: 4 feet of York stone ($2\frac{1}{2}$-in.) laid next a 12-inch by 8-inch curb, this formed the permanent path, the inside space being paved with tar or other like material, this gave a 24-feet road from curb to curb. He found that the repair of macadamised roads came to a little more than Mr. Strachan had stated. The picking up and levelling cost about 2*d.* per square yard and the covering of metal varied from 9*d.* to 1*s.* per square yard, according to the class of material used. The rolling varied from $1\frac{1}{2}$*d.* to $2\frac{1}{4}$*d.* per square yard, according to the traffic which was passing over the road and causing stoppage of the steam roller during the progress of the work. These items brought up the total cost to about 1*s.* 3*d.* per square yard. Mr. Strachan put it down at 1*s.* He had about half a mile of wood paving in the Edgware Road, of which the first cost was 9*s.* 10*d.* per square yard. It had been down about three years. It had been necessary to repair certain portions and he did not think that he could calculate on seeing that wood pavement in anything like good condition at the end of its eighth year.

Mr. W. N. Colam said that during the summer months he had noticed some very objectionable smells arising from wood paving, especially in the vicinity of cab ranks. His idea was that the wood absorbed the urine during the greater part of the year, and gave it out in hot weather. He did not agree with the author that granite setts could not be laid directly on a solid concrete foundation. No doubt there would be great difficulty in making stones so true to gauge as to be able to lay them on a hard concrete foundation and preserve a true surface in the road, if the concrete was allowed to get hard before the stones were put down; but he had seen very good practice where a concrete foundation was used, and that was to put a thin layer of plastic concrete upon it, and before that had time to set the stones were bedded upon it, and any inequalities of the sett stones were made up by the plastic concrete. There was a very good instance of this method in Highgate at the

present time, in the case of a stone paving laid five years ago, and which had had nothing done to it since, and is now in excellent order. He did not approve of creosoting the wood blocks for roads. The effect of creosoting was to seal up the moisture which was practically always to be found inside the wood, whereby in course of time the block rotted and collapsed in the centre, and the crown subsided and caused unpleasant hollows in the road. The reason why the tram roads in Melbourne were worn less by comparison with European tracks was, he thought, probably not so much due to the class of wood used, as to the fact that the streets were enormously wide, and the tramways had practically a monopoly of their own roads, consequently the street traffic scarcely ever interfered with the tram lines. This would account for absence of rutting.

Mr. J. W. Wilson, Jun., thought that the discussion should not close without some reference to a paper which was read before the Society eleven years previously by Mr. Copland upon a somewhat similar subject. It was interesting in this way to note the progress which had been made since that time. On that occasion a description of the history of road making was given, and many different methods of construction were brought forward and considered, of which they had scarcely heard anything to-night. He supposed that they might look upon the matter as a case of the "survival of the fittest." They might probably take it that the experience of the last eleven years had shown what was the best practice for road "construction and repairs" under modern traffic conditions; and for this reason, amongst others, the paper they had just heard could not fail to prove of permanent value.

Mr. G. W. Thompson said that his experience was decidedly that as a general rule wood paving did not last for eight years. He had three roads which were paved with wood about six years ago; the blocks in two of these roads would shortly have to be taken up. With regard to asphalte he did not think that he should like to use it for the paving of any of the streets in his district. He certainly should not like to use it in Tooley Street. It was altogether too slippery. As to macadam he had always broken the material to $2\frac{1}{2}$ inches. He agreed with Mr. Barber with regard to the use of rag-stone, and expressed his regret at not having seen a digest of the paper, as he should much have liked to go more fully into the subject.

Mr. Henry Faija said that Mr. Strachan seemed to make a feature of foundations. He thought that Mr. Strachan ought to be careful about laying half an inch of fine on the top of $5\frac{1}{2}$ inches of core. If this fine layer is laid on the rough bottom after the bottom has set, it would not bind or adhere to it

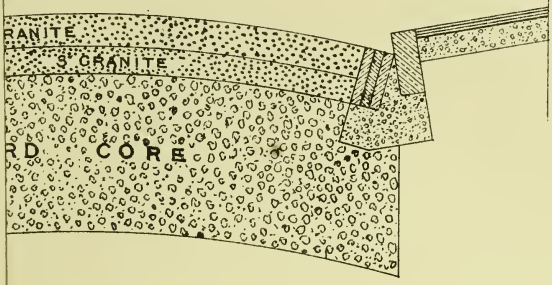
thoroughly, and would become a thin independent stratum, which would receive all the impact of the traffic, and would be therefore liable to destruction. If, on the other hand, it is laid on the rough bottom before that is set, it would form one homogeneous mass, and the permanency of the road would be secured. There was a pernicious practice to which road contractors were addicted of using old macadam as the matrix of the concrete. This was not washed; it was nasty dirty stuff, which destroyed the value of the cement immensely. As to the difference of the value between good cement and bad cement, there was no comparison between them. Good cement did its work and bad did not. The cement used on a road must, to a certain extent, be a quick-setting cement, because it was desirable to reopen the road for traffic as soon as possible, and quick-setting cement was not necessarily the best.

Mr. J. H. CUNNINGHAM, referring to the slipperiness of certain roads, suggested that the cure was to be found in an altered method of shoeing horses. He believed that if horses were shod so as to allow the frog to come to the ground, they would not slip on any pavement. Possibly the cure for slipperiness might be found in that direction, rather than in attempting to modify the smooth surface of asphalte pavements.

Mr. STRACHAN made the following communication in reply, viz.:—The division of a road into one-third for footway and two-thirds for carriageway, is an empirical standard, and is not therefore capable of being scientifically demonstrated, but in its favour it may be pointed out that pedestrians can pass each other more readily and in less space than vehicles, and therefore the latter are entitled to more favourable consideration than the former. In a 40-foot road, this rule allows three vehicles to pass with safety, whereas an increased width to the footway would prevent this. The size to which macadam should be broken is another empirical matter. In light traffic 2-inch stones are no doubt preferable to larger stones, but in metropolitan traffic they do not give body enough to carry the weight with economy. The segmental section was adopted because the templates could easily be made true in shape by an ordinary carpenter, and as a consequence, a road could be made to the required contour with certainty by the men ordinarily employed. It is the author's practice to make templates for each part of a road which increases in width one foot or more from the narrowest part. In the case of sidelong roads, the cross-section is made a straight line when paving is used, and thus the difficulty of junctions is avoided. The eight years' life given to wood pavement is the Chelsea experience. In fact, there are, at the moment of writing, 11,491 square yards of

wood pavement in Chelsea which have been laid ten years under a traffic weight of 500 to 600 tons per yard in width every 16 hours. The steepest gradient at which the writer has laid wood pavement is 1 in 33 for a short length. In dry weather such a gradient produces no difficulty, but in frost or "greasy" weather the difficulty is pronounced. In answer to Mr. Barber's questions as to the Jarrah wood, the writer hesitates to express an opinion as to its suitability for wood paving, as the sample laid in Chelsea has only been down twelve months; but so far as it has shown its characteristics, he would say that it is much more noisy than yellow deal, that the joints show a tendency to spread, and so afford a harbour for dirt, and that it is more slippery than deal. It is very questionable whether the Jarrah timber is suitable for a wide application as a wood pavement, but its advantages appear to place it as a suitable material for paving tramways, affording as it does a compromise between the conflicting interests of the companies who require long life to the pavements, and the local authorities who require something less noisy than stone.

Fig. 6.



MAKING TEMPLATES.

Fig. 7.

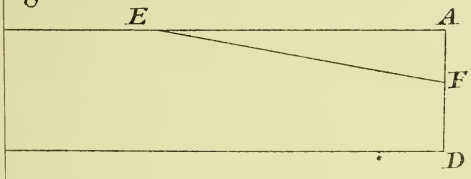
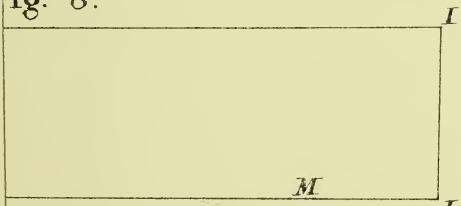
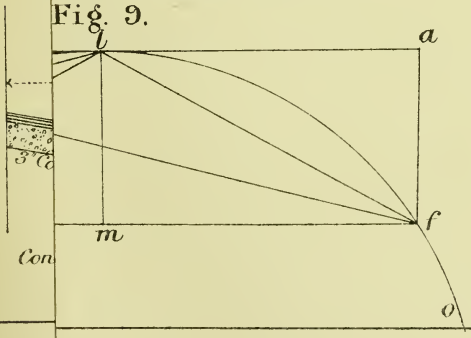


Fig. 8.



MAKING TEMPLATES.

Fig. 9.



Mc Adam road (His earliest form)

Fig. 1.

Mc Adam road (later form)

Fig. 2.

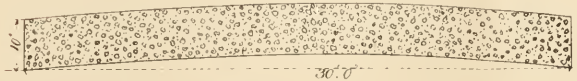


Fig. 3.

Distribution of Weight on Mc Adam road.

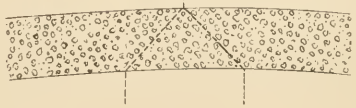


Fig. 4.

A. Telford road.

Fig. 5.

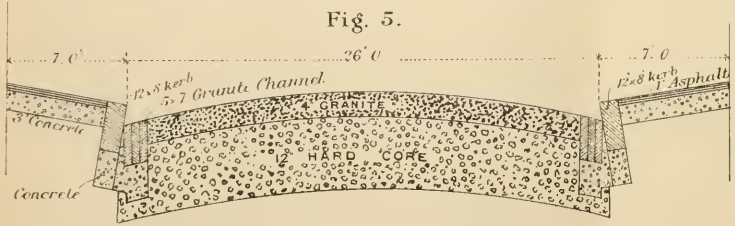
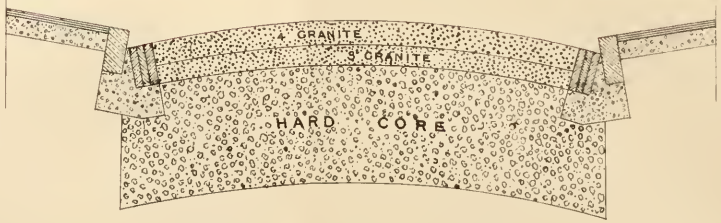


Fig. 6.



METHOD OF MAKING TEMPLATES.

Fig. 7.

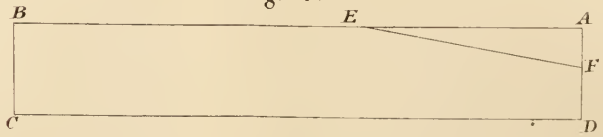
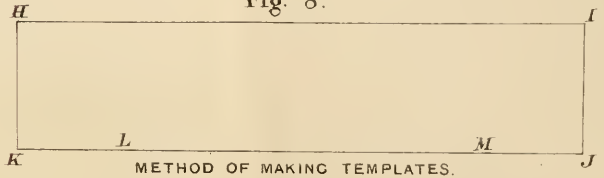
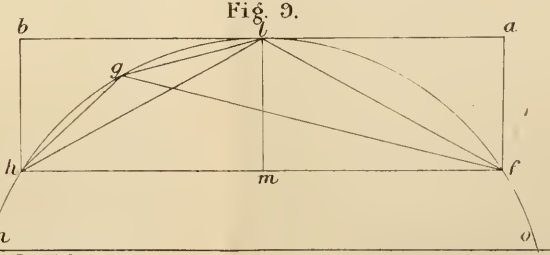


Fig. 8.



METHOD OF MAKING TEMPLATES.

Fig. 9.



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JONATHAN R. BAILLIE, PRESIDENT, IN THE CHAIR.

FIREPROOF FLOORS.

BY G. M. LAWFORD, ASSOC. M. INST. C.E.

THE subject of fireproof flooring is apparently one of great antiquity, for the Romans in the time of Julius Cæsar were in the habit of making their floors and roofs, as well as their walls, of concrete. From an article in Vol. LI. of 'Archæologia,' in the possession of the Society of Antiquaries, it appears that large beds of pozzolana existed over the area of the Campagna. This substance, as is well known, when mixed with lime, forms a natural hydraulic cement of great cohesive power. The lime employed was obtained by burning "travertine" (*lapis Tiburtinus*); and the other ingredients of the concrete usually consisted of broken lumps of tufa for walls and ordinary foundations, of broken lava when foundations of great strength were required, and of lumps of broken pumice for arched roofs and vaults, where lightness was essential. The floors were constructed of large slabs of concrete resting on sleeper walls of brick 2 feet 9 inches high and about 14 inches thick, set in clay and placed about 3 feet apart, a layer of fine concrete being spread over the slab, and mosaic paving bedded thereon. The roofs were made flat and supported on brick pillars. It is apparently a matter of question whether flat centering was used, or concrete slabs in the manner described.

Coming nearer to our own times, up to the middle of the eighteenth century fireproof flooring seemed to consist only of the brick arch with its accompanying disadvantages of enormously thick walls and great cost, but, towards the close of that century, cast iron-girders and segmental brick arches were gradually coming into use for warehouses and floors where strength was essential.

In 1788, Earl Stanhope, in a paper read before the Royal Society, described his invention of pugging for rendering wooden floors fireproof; but this had, in a way, been preceded by the floors used in Nottingham and the surrounding districts in the seventeenth century, formed entirely of bundles of reeds

covered with a thick layer of coarse-gauged gypsum, and plastered below with the same material. In Earl Stanhope's floor, fillets were nailed to the joists at about one-third of the height; laths were laid on the fillets and plastered above and below with a mixture of lime plaster and chopped hay; a liquid grout was run over both sides covering the fillets, thereby forming a fire-and air-proof slab, and the undersides of the joints being then lathed and plastered to form the ceiling. About 1820, wrought-iron joists began to take the place of the cast-iron girders, and the arch was reduced to a single half-brick ring, concreted over the haunches. This method was followed by a floor, designed by a Dr. Fox of Bristol, about 1830, in which wooden fillets were laid on the lower flanges of rolled joists and concreted over, being known as the "Fox and Barrett" floor, and was the subject of a paper read before the Institution of Civil Engineers by Mr. Barrett in 1849. Here it may be remarked, that although the subject is common ground to both engineers and architects, an interval of forty years has been allowed to elapse without the subject being reopened before the Institution, while the present paper is the first on the subject that has been read before the Society of Engineers.

A description of the "Fox and Barrett" floor will be given later, but it should here be observed that this floor was the first in which an attempt was made to protect the exposed faces of the iron joists with a fire-resisting material.

In 1845, the late Sir Henry Hunt brought in a system of arching in which the latter was composed of tiles and cement resting on rolled joists. In 1862, Messrs. Measures introduced an improved modification of the "Fox and Barrett" floors, known as Phillips's floor, in which tee-iron bearers, 9 inches apart, were substituted for the wooden fillets, and this was followed by the different developments and applications of wrought iron and concrete now in general use.

The objects of fireproof flooring are:—To render each floor capable of resisting the effects of fire, and by so doing to divide the building into a series of compartments, so that fire can neither be communicated from one compartment to another, nor from one story to another, and by making the roof fireproof in addition, to prevent fire from spreading from one compartment to another by the roof burning away. To gain strength, and in so doing to avoid as far as possible lateral thrust on the walls, and, by making the floor in one homogeneous mass, to distribute the weight equally over them. To render the floors sound-proof as well as fire-proof; and, lastly, to secure the building from the attacks and effects of both dry rot and damp.

The systems now most in use in English practice appear to be :—

(1) The concrete arch floor.
(2) The flat or suspended concrete floor.
(3) The arch-block or American floor.
(4) The flat brick or French floor.
(5) The solid wooden floor.

The following systems are described in detail as examples of the different types of construction :—

Messrs. Dennett's and Wilkinson's, representing the concrete arch floor; Messrs. Dawnay's, Lindsay's, and Gardner's, representing the flat concrete floor; Messrs. Doulton's (the Doulton-Peto), representing the arch-block or American floor; Messrs. Homan and Rodgers', representing the flat brick or French floor ; and Messrs. Evans and Swain's, representing the solid wooden floor.

Taking them in the order given, the inventors of the Dennett fire-proof construction rely for the resistance to fire offered by their system on the properties of sulphate of lime (gypsum). Ordinary limestone cements, when exposed to the action of fire, lose their cohesive power and tend to fly, thus resembling the original carbonate; but experiments have proved that sulphate of lime loses little of its cohesion by calcination, and that it will remain intact even when exposed to a white heat, and to the application of cold water while in that state, though it is necessarily considerably weakened; in fact it may be said to resemble timber under the action of fire. The outside, becoming charred, serves as a protection to the inside.

The system consists of concrete arches supported by walls for narrow spans and by rolled joists for wider spans. The concrete is composed of broken brick and sulphate of lime. The arches are given a minimum rise of 1 inch to every foot of width up to spans of 10 feet. The concrete can either be filled in solid over the haunches to form a floor of the same material throughout, or arranged to carry a wooden floor. Where columns and main girders are required, both are completely encased in the concrete, while the ceilings can either be plastered, or ceiling joists can be placed on the lower flanges of the joists, and lathed and plastered.

From the slight rise given to the arches the thrust on the outer walls is reduced to a minimum.

This floor can be laid as a flat floor if required, but the usual construction is that of the arch.

The concrete of which these floors are composed is a non-conductor of both so[illegible]eat. As an instance of its great strength, on one o[illegible] building was being erected, a

scaffold pole fell vertically from a great height on to an arch of this concrete and knocked a hole through it exactly the size of the pole. The minutest examination failed to discover anything approaching a fracture or crack, either in the concrete immediately surrounding the hole or at any other point in the arch.

The long list of buildings in which the Dennett construction has been adopted shows the high opinion in which it is held. Mention may be made of the Home, Colonial, and Foreign Offices, the National Gallery, St. Thomas's Hospital, the Law Courts in London and Birmingham, and the Imperial Institute.

The cost of this floor for a 12-foot bearing and a 10-foot span of arch, inclusive of joists, is 9*s.* 3*d.* per square yard: the weight is 54 lbs. per square foot, and the safe load 2 cwt. per square foot.

Messrs. W. B. Wilkinson & Co. have two systems for fireproof floors, one of concrete arches similar to the Dennett construction, and the other a protection to wooden flooring, consisting of fibrous plaster slabs laid as pugging between joists, and thinner ceiling slabs of the same material.

Referring to the first system, the concrete of which the arches are made is composed of bricks broken to 1½ inch gauge, coke breeze, and Portland cement. The form of arch is similar to the Dennett construction; main girders and columns, when used, are covered with Wilkinson's fibrous plaster (described later).

The floors can be finished entirely in concrete, or arranged for wood, tile, or other paving.

For landings, corridors, and similar small spans, no joists are required, the concrete being laid on flat centering; additional strength is given by the insertion in the concrete of tee-irons 2 feet 6 inches apart.

Ceilings can either be finished off with plaster, or laid with ceiling joists, to which are nailed fibrous plaster ceiling slabs ⅝-inch thick.

This system has been used at Edinburgh University, at several stations on the North-Eastern Railway, by the War Department, and in many warehouses and stables.

The cost of this floor, for a 12-foot bearing and 10-foot span of arch, inclusive of joists, is 7*s.* 6*d.* per square yard; the weight is 52 lbs. per square foot, and the safe load 2 cwt. per square foot.

The second system, Fig. 1, is suitable for dwelling-houses, offices, &c., and has the additional advantage that it can be adapted to any existing wood

In construction it is similar to the pugging invented by Earl Stanhope, and described previously; slabs of fibrous plaster pugging are nailed to wooden angle fillets on the joists, and a triangular plaster fillet is then run along the slab against the joist. The floor is boarded over in the usual way, while the ceiling consists of fibrous plaster ceiling slabs nailed to the joists; all joints are carefully plastered and a series of air-tight compartments is thus produced. The slabs for both pugging and ceiling are made of coke breeze and plaster on a basis of cocoa-nut fibre; they are non-inflammable, and by reason of their lightness are specially adapted for wooden floors, as the walls can be of the usual thickness, while concrete floors must be supported by much stronger walls.

The cost of pugging and ceiling is about 5*s.* per square yard, exclusive of timber construction.

Mr. A. D. Dawnay is one of the pioneers of the flat or suspended concrete floor. His system consists either of ½-inch square iron bars 12 inches apart, or of small 3-inch joists, 16 inches apart, resting on the lower flanges of 5-inch binding joists in 7-foot bays. This construction is suitable for spans up to 20 feet wide, the binding joists being strengthened according to the increase of span.

Flat centering is placed below the joints, and concrete is filled in, forming one solid mass completely encasing the iron work. The concrete is composed entirely of broken brick, (crushed firebrick being preferred), and Portland cement. The joists are protected with a minimum depth of 1½ inch of concrete.

Any floor can be laid on the concrete, while the ceiling can either be floated or plastered.

The chief advantage lies in the fact that this floor is composed of a solid block, of one material throughout, absolutely indestructible, of great strength, and of the simplest type of construction.

Mr. Dawnay's system has been used in over 3000 buildings, amongst others Charing Cross Hotel, the Colonial Institute, Exeter Hall, the Gaiety Theatre and Restaurant, London and County Bank head office and branches, several Board Schools, Salvage Corps and Fire Brigade stations.

The cost of this floor, for a 12-foot bearing, including joists, is 7*s.* per square yard, the weight is 40 lbs. per square foot, and the safe load 2 cwt. per square foot.

Messrs. W. H. Lindsay & Co., of Paddington, also use the flat construction. The joists are spaced from 18 inches to 36 inches apart, additional strength being given to both concrete and joists by means of trussed rods: these are placed in pairs on the joists

about 18 inches apart, and pass over and under them, thus having the effect of bracing the joists. The ends of the rods are bent over to form a clip on the flange of the joists, as shown in the diagram (Figs. 2, 3, and 4).

One great advantage claimed for these rods by the inventor is, that if any portions of the concrete give way under fire, the rods keep the whole slab from falling, and the damaged parts can afterwards be cut away and made good.

The concrete used is Lindsay's patent pumice concrete, consisting of coke breeze, mineral sand, and Portland cement; it weighs 80 lbs. per cubic foot, as against 112 lbs. for ballast concrete and 100 lbs. for brick concrete, and materially lightens the weight of the whole floor. The floor and ceiling can be finished in any of the usual methods. The cost of this floor, for a 12-foot bearing, including joists, is 7*s.* per square yard, the weight is 44 lbs. per square foot, and the safe load 2 cwt. per square foot.

Messrs. Lindsay & Co. have another system of fireproof flooring for use where greater strength is required (Figs. 5 and 6). The patentees' steel floor troughs are used and filled with pumice concrete, the underside being protected either by a lath and plaster ceiling secured to fillets bolted to the troughs, or by pumice concrete slabs suspended in the same way.

This flooring is considerably more expensive, and a great disadvantage lies in the fact that the whole surface, though sheathed, is practically a sheet of metal, and, therefore, would be sooner affected by fire than the other system.

These floors have been used in the National Liberal Club, the Prudential Assurance Co.'s offices, Holborn, in several blocks of Artisans' dwellings, warehouses, offices, and mansions.

Messrs. Gardner, Anderson, and Clarke's system is practically Lindsay's floor with the trussed rods omitted, the concrete used consisting entirely of coke breeze and Portland cement. The joists are spaced out, flat centering is slung to them, and concrete filled in to a depth of 1 inch below the joist and 1 inch above the top flange. The joists are thus completely embedded in a non-conducting material. This floor, owing to its light construction, has been largely used for shops with dwellings above them.

The cost of this floor, for a 12-foot bearing, including joists, is 7*s.* per square yard, the weight is 46 lbs. per square foot, and the safe load 2 cwt. per square foot.

The Doulton-Peto floor (Fig. 7) is of arch construction but the arch is perfectly flat, consisting of a series of terra-cotta blocks completely encasing the joists or girders. It is composed of springers or skewbacks resting on and overlapping the lower flange, and of a wedge-shaped key-block, the intervening blocks being rhomboids.

The blocks are composed of a mixture of clay and terra-cotta, and are moulded with dovetail grooves on the lower surface, to afford a key for plaster. The material of which the blocks are made does not crack, either under heat or from the effects of cold water during heat, while the joist or girder is completely covered with the same material, which is a great non-conductor of heat, and on this account has been used for Turkish baths.

It must, however, be borne in mind that there is a considerable amount of thrust, involving the use of stronger walls, while a layer of concrete or dry filling has to be added to complete it, and, from the nature of the construction, the spans cannot exceed 6 feet without increasing the depth.

It has been used at Whiteley's, the London Pavilion, the head office of the National Provincial Bank, and in several warehouses.

The cost of a 6-inch floor for a 12-foot bearing and 6-foot span of arch, inclusive of joists, is 9*s.* per square yard; the weight is 34 lbs. per square foot, and the safe load 2 cwt. per square foot.

The Homan and Rodgers' floor (Figs. 8 and 9) is an application of the French, or flat brick floor; the arch construction is avoided, and the flooring, being a dead weight, serves to tie and strengthen the walls. The system consists of rolled joists placed 3 feet 6 inches apart. Resting on the lower flanges of the joists, the iron bearers are laid, 12 inches apart, the ends being bent up so that the undersides of the joists and tee-irons are on the same level. Specially-moulded hard-burnt bricks are then laid on the tee-irons. These bricks are of gault clay, and are perforated for lightness; they are 12 inches long, $4\frac{1}{2}$ inches wide tapering to 3 inches, and $2\frac{1}{2}$ inches deep, and are made with wedge joints longitudinally and dovetail joints transversely, as shown in the diagram; they are moulded with longitudinal dovetail grooves on both surfaces to afford a grip for the concrete and a key for the plaster. A depth of $2\frac{1}{2}$ inches of coke breeze concrete is laid over the bricks; this fills up the wedge-joints and binds the whole into a solid mass.

The soffit is then plastered, the grooves on the bricks forming a sufficient key to carry the plaster under the joists and tee-iron bearers, thus covering all exposed surfaces of the ironwork.

The floor can be finished as required. The bricks are not affected by heat, and are protected from the effects of water by the concrete above and the plaster below.

The floor is practically noiseless, the different densities of the brick, concrete, and plaster intercepting the sound vibrations.

An additional advantage is in the diminished depth of the floor, owing to the absence of the arch.

These floors have been used by the London School Board, and in the General Post Office, the People's Palace, and several large blocks of mansions and warehouses.

The cost of this floor, for a 12-foot bearing, including joists, is 7*s.* per square yard, the weight is 35 lbs. per square foot, and the safe load 2 cwt. per square foot.*

Messrs. Evans and Swain's fire-proof construction depends on the known resistance offered to fire by solid timber. As is well known, where flames are not able to play round timber or attack it at the ends, a very great resistance is offered to the action of fire, and after charring to a certain depth, the charcoal formed on its surface becomes its protection, charcoal being a non-conductor of heat.

It is also a well-known fact that common plaster offers great resistance to fire, and upon the application of these two facts depends the success of this system, for which the inventors claim strength, simplicity of construction, and almost perfect resistance to fire. An additional claim also deserves recognition, namely, that floors constructed on this system, being homogeneous throughout, the whole weight is a dead weight, and consequently there is no thrust on the walls.

The flooring consists of solid wooden joists of uniform depth and thickness, closely laid, without any intervening space whatever, and spiked together; the spikes should be driven about 18 inches apart and placed as in chain rivetting. It is preferable to bore holes for the spikes to prevent splitting.

The depth of the joists varies from $4\frac{1}{2}$ inches in spans of 8 feet, to 11 inches in spans of 30 feet. The ends of the joists bear on the walls in the usual way, only no plates are required.

All cracks or shrinkages on the upper surface are filled up with a grouting of liquid plaster, while the ceiling can be formed either by nailing the laths direct to the joists, or to fillets on the joists; or the lathing can be dispensed with by grooving the undersides of the joists to form a series of dovetails which afford a key, and the ceiling can then be plastered.

* Since this paper was written, Messrs. Homan and Rodgers have produced an improved modification of their system (see Figs. 10 and 11) in which the tee-irons and flat bricks are superseded by hog-backed bricks 18 inches long, reaching from joist to joist, and clipping the lower flanges. These bricks are of the same transverse section as those used in the first system, but are hog-backed longitudinally, with rounded ends recessed to receive the joists, and perforated transversely for lightness. Both surfaces have similar dovetailed grooves. The floor is finished with breeze concrete up to the level of the joist. This system is certainly an advance on that last described, as the tee-irons are dispensed with entirely, and the joists, though closer together, are protected by the jaws of the bricks. The cost of this floor, for a 12-feet bearing, is 6*s.* 6*d.* per square yard, and the weight 32 lbs. per square foot.

As an additional protection the joists can be tongued, but this, of course, adds to the expense.

The upper surface of the floor can either be left rough, boarded, or floated and finished as a tile or concrete floor, but a layer of hair-felt on which floor boards are laid serves not only to deaden sound, but also to increase the resistance to fire.

An excellent feature of this flooring is that it dispenses entirely with the use of iron, the action of which under fire is well known.

Owing to its great strength, it has been largely used for dock and railway warehouses, amongst others the recently completed warehouses in Commercial Road, E., for the London, Tilbury, and Southend Railway Company, and for warehouses at the East and West India Docks, while it is now being used in the additions to Westminster Hall.

Illustrations are appended, see Figs. 12 to 15.

The cost of a 5½-inch floor, for a 12-foot bearing, is 10*s.* 6*d.* per square yard; the weight is 20 lbs. per square foot, and the safe load 7 cwt. per square foot.

A table giving approximately the relative cost, weight, and safe load of a floor of 12-foot span, in the different systems, is appended.

To make this paper more complete, reference must be made briefly to other systems which have been introduced from time to time with varying success.

The "Fox and Barrett" floor, alluded to previously, consisted of rolled joists placed about 20 inches apart. On the bottom flanges strips of wood 1¼ inch square were laid about ½ inch apart; concrete was then filled in between the joists and the ceiling plastered, a key being afforded by the undersides of the fillets.

Messrs. Measures introduced and patented a modification of this floor, in which the joists were placed from 3 feet to 4 feet apart, and tee-iron bearers 9 inches apart were substituted for the wooden fillets. The floor was then concreted on flat centering and the ceiling plastered. This system was used extensively in London and elsewhere from fifteen to twenty years ago.

Hornblower's floor consisted of a series of fire-clay tubes resting in arch construction on larger tubes of the same material filled with fine concrete, and strengthened with tension rods secured to the walls.

Mr. Mark Fawcett has recently introduced a modification of the "Hornblower" floor, in which rolled joists are placed 2 feet apart. Resting on the bottom flanges and encasing

them, semi-circular tubes of fire-clay, 4½ inches diameter and 1 inch thick, called by the inventor "tubular lintels," are laid diagonally. The flat, or lower surface, has a projecting lip or flange forming a wedge-joint with the flange of the next tube. The whole is concreted over with breeze concrete and the ceiling plastered, the flat side being grooved in the same way as the bricks used by Messrs. Homan and Rodgers. A diagram is appended (see Figs. 16 and 17). The cost, including joists, for a floor, 12 feet bearing, is 8*s.* 6*d.* per square yard, and the weight is 40 lbs. per square foot.

Allen's system consisted of a network of iron bars forming meshes 2 feet square, covered with concrete. Iron bars, 3 inches by 1 inch, placed 2 feet apart, were built into the walls; on these, and wired to them, were laid ½-inch iron rods, also 2 feet apart. Flat centering was placed under this, and concrete to a depth of 4 inches was laid on. The concrete was composed of 4 parts of crushed slag or clinker to 1 part of Portland cement.

Clark Bunnett's floor is of the flat floor and joist type, but wooden fillets are laid across the top flanges of the joists and clipped to them. Concrete is spread on flat centering and brought level with the top of the fillets; a layer of mastic is then run over the whole surface, which is finished off with wood blocks, or floor-boards nailed to the fillets through the mastic. The ceiling is plastered in the usual way. An illustration of this floor is appended.

Moreland's system, and that recommended by the late Sir William Fairbairn, may be taken together; as in both cases girders were used with arched iron plates carrying the concrete, the construction being that of a concrete arch with an iron lining to the soffit, and both, of course, were open to this great objection, that a large surface of iron was directly exposed to the attacks of fire.

French systems.—One of the earlier French floors was that known as "Thuasne's." It consisted of rolled joists placed 3 feet apart. Resting on the lower flanges were laid flat iron bars or inter-ties, the ends being secured by pins to straps passing over the joists. Iron bars ½-inch square, called "fautons," were laid 9 inches apart transversely on the inter-ties and were wired to them; flat centering was placed under the joists and a 3-inch layer of coarse plaster of Paris was poured over the whole surface. A boarded floor was then laid on the girders.

Several modifications and improvements on this system have been made from time to time by French architects, and among them is one much in vogue at the present time in Paris, in

which the joists and inter-ties are retained, the latter being placed 9 inches apart. Bricks on edge are laid on the inter-ties and are then plastered on both sides. The Homan and Rodgers' floor is an application of this system.

M. Zorés exhibited a floor, in the Paris Exhibition of 1857, on the arch and girder system, which has been much used in France. The girder consisted of wrought iron rolled in the form of an inverted flanged trough These girders were placed 2 feet 8 inches apart, and the arch was composed either of perforated bricks or of hollow plaster blocks, in either case concreted above and plastered below. The American system has also been adopted in a modified form in Paris, moulded perforated bricks taking the place of the terra-cotta blocks.

American systems.—From papers on the subject read before the Royal Institute of British Architects by Mr. Gale in 1882 and Mr. Gass in 1886, the general system in America appears to consist of rolled joists and hollow arch-blocks of a hard-burnt clay resembling terra-cotta or fire-clay, the joists being protected by skewback blocks with projecting lower members.

Another system consists of rolled joints and segmental hard brick arches; the bricks used are 8 inches by 4 inches by $2\frac{1}{2}$ inches, and are of unusual hardness. The joists are protected by terra-cotta tiles fixed to the flanges by mortar.

In both these systems a thin layer of cinder concrete is spread over the arch, and the floor is laid on this. The system of arch-blocks and joists has been patented in England by Messrs. Doulton.

Pugging is also very largely used in America for fireproofing wooden floors. It consists of bricks laid flat on fillets between wood joists, and covered with a thin layer of cinder concrete. The joists are boarded over the top, and the ceiling is formed with either terra-cotta or cement tiles clipped to the joists by iron plates and well plastered at the joints.

Mention may be made of the so-called fireproof plasters and paints which doubtless tend to retard the action of fire, owing to their being made of fire-resisting substances.

Robinson's plaster and the Hitchens Company's plaster are mainly composed of gypsum, and rely on this for their resistance to fire as opposed to the ordinary lime plasters; in the Hitchens's plaster slag wool is used in addition.

The Cyanite Company have produced a paint the principal ingredient of which is silica, a metal which has long been known for its great powers of resistance to fire. This paint is, no doubt, a great protection to exposed timber.

Asbestos is another material which can be used either in the

form of plaster or paint, but its properties are more of a non-conducting than fire-resisting nature.

Slag wool and slag cement, now both in their infancy, are also coming into use in fire-resisting construction. There is little doubt that slag cement, which is rapidly supplanting Portland cement in Germany, will shortly be largely used for concrete floors in this country. It is both cheaper and lighter than Portland cement, and when mixed with sand is considerably stronger, while its fire-resisting properties exceed those of either gypsum or Portland cement.

Taking the relative merits and defects of the different floors into consideration, it will perhaps be better to deal with the individual floors first, and then to contrast the types of construction.

Comparing the arched systems, in both the Dennett and Wilkinson floors, brick forms the basis of the concrete, the resistance to fire depending in the one case on gypsum, and in the other on Portland cement. Of the two, gypsum affords the greater resistance and is the lighter, but its cohesive power being less, the concrete has to be made in stronger proportion; hence the increased cost.

In both systems the weak point appears to be the want of protection to the joist, which is dependent on a plaster covering. The Doulton floor overcomes this feature in a way as effectual as any, and this is a very strong point in its favour; its disadvantages are that it requires a layer of concrete or dry filling over the top to make it air- and water-tight, thus forming two layers of different materials, one of which is more affected by heat than the other; that it cannot be used in such wide spans as either of the others without increasing the depth, and consequently the cost; and, lastly, that there is a considerable amount of thrust. The lightness is much in its favour, but the extra concrete or filling, and the greater number of joists required must be borne in mind when comparing it with the others. Of the three, the Dennett floor has, undoubtedly, popular opinion in its favour, but apparently a good fire-resisting floor of arch construction could be made by a combination of the Dennett and Doulton floors, the joists being protected by the Doulton terra-cotta blocks covering the flanges and acting as springers to an arch of Dennett concrete.

The three flat floors, again, differ mainly in concrete. The use of trussed rods in Lindsay's system doubtless strengthens both joists and concrete, but at the expense of an increase of metal, thereby giving an additional chance to fire. The nature of the flat construction is a series of suspended landings or slabs, supported by joists and completely encasing them, thus forming

a homogeneous mass which acts as a dead weight on the walls or supports, dispensing entirely with thrust, and serving to tie in the walls.

The three are identical in cost and safe load, the difference in weight being in favour of Dawnay's; and for resistance to fire, preference must also be given to Dawnay's, the concrete of which is composed entirely of broken brick and Portland cement, the former giving more resistance than coke breeze, on which both Lindsay's and Gardner's depend.

The Homan and Rodgers floor is of the flat construction type, bricks supported by iron bearers taking the place of the solid concrete slab. This floor is considerably lighter than any one of the other three, and not much more expensive, but the additional metal of the tee-irons is certainly against it, as, although protected by plaster, directly the iron goes the bricks follow, while the tee-irons would also give a vibratory effect to the floor when used for moving loads. Another defect is, that when constructed this floor is in layers of materials differently affected by heat. Its lightness and shallowness are, however, both in its favour.

Coming lastly to Evans and Swain's floor, the chief disadvantage is the cost; but for strength and lightness it is inferior to none. It can be used in as wide spans as any of the others without intermediate supports, is more homogeneous, and requires less strength in the walls than the concrete and iron floors. A grave disadvantage is the liability to dry rot, as the floor being a solid mass of timber, if dry rot once obtained a hold, it would be next to impossible to prevent it from spreading without frequently removing the floor and ceiling for inspection, and thereby creating a kind of charge for maintenance which is not required in any of the other systems; but as a fire-resisting medium, the density of this floor, coupled with the absence of iron, renders it as effective as any.

Contrasting the arched and flat floors, it is obvious that the use of the flat floor involves more joists, as the concrete slabs, being virtually beams supported at both ends, cannot be used in such wide spans as the arch, the joists in the latter being from 7 feet to 10 feet apart, while in the former the average is from 18 inches to 3 feet, thus involving the use of more iron; but, on the other hand, the concrete casing of the flat floor forms a better protection than the plaster covering of the joists in the arched floor.

The action of the arches pressing against each other no doubt tends to brace and strengthen the joists laterally, but against this there is the thrust on the outer walls and the increased weight of the joists, which have to carry a much greater load

than in the flat floors, and consequently add to the weight on the walls or supports. The head-room required for the arch is also a serious consideration when opposed to the shallow depth of the flat floors.

In the matters of cost and weight the advantage certainly lies with the flat floors, while for safe load, with the exception of Evans and Swain's, which is lighter and stronger than any, there is nothing to choose between either arched or flat construction, the strength depending on the joists used.

In summing up the relative values of the different floors there appear to be two leading features for consideration:—

Firstly. Which system gives most protection to the ironwork supporting the floor?

Secondly. Which of the different materials employed gives most resistance to fire?

As regards the first question, Evans and Swain's floor, requiring no ironwork, stands by itself; but next to it, and certainly in advance of all the others, on this one point, must be placed Doulton's floor, the hard-burnt blocks with their overlapping bases forming a most efficient protection to the joist. There is little to choose between the different concrete floors on this point, as in the case of the arched floors there are comparatively few joists dependent on a plaster covering, while in the case of the flat floors there are from four to six times the number of joists, which are, however, completely embedded in concrete. The Homan and Rodgers' floor has more ironwork than any of the others, both joists and tee-irons depending entirely on a plaster ceiling.

On the second question, taking the cements first, gypsum gives more resistance to fire than Portland cement, but at the expense of strength. The other materials to be considered are coke breeze, solid wood, and clay in the three forms of terra-cotta blocks, broken brick, and brickwork as in the Homan and Rodgers' floor. In any of these three forms, clay is better than coke breeze, as the latter, under the influence of intense heat, such as that in the midst of a building on fire (stated by Captain Shaw to be from 2000° to 3000° Fahrenheit), will gradually calcine and burn away, while the tendency of clay is to become harder. Another disadvantage of coke breeze used as concrete is its porosity.

The impervious mass of the wooden floor, well protected by plaster, should render it as capable of resisting fire as either of the other materials, though it would no doubt share the fate of coke breeze under a fire of similar intensity; but there being no ironwork in it to give way, it is entitled to the preference over coke-breeze, and though by its nature more inflammable

than either terra-cotta or brick concrete floors, on the same ground (namely, the absence of iron), it would probably give as much resistance as either of the last-mentioned floors.

Mr. William Lindsay, jun., has recently designed and patented a fireproof floor (Figs. 18 and 19), which, although it has not yet been used, apparently fulfils the two requirements laid down by the author, and therefore deserves recognition in this paper, while the cost and weight compare favourably with the systems already described.

The floor is of the flat brick type, and consists of steel joists, placed 2 feet apart, with rectangular hollow bricks suspended to them by means of a jaw or recess at each end. The bricks are 2 feet long, 4 inches wide, and $4\frac{1}{2}$ inches deep, with a central horizontal web running from end to end, the thickness of the sides and web being half an inch; they are moulded with longitudinal dovetailed grooves on both surfaces, to afford the necessary key for plaster and concrete, while a bond is obtained by means of a wedge-shaped boss or projection running the full length of the brick, fitting into a corresponding recess on the next brick, and forming a joggle, as shown in the accompanying diagram. The lower flange of the joist is protected by a narrow tile resting on the jaw of the brick, while the upper flange is covered with a rectangular channel pipe made of the same clay as the bricks, and bedded in the concrete covering. The underside is then plastered, while the floor can be finished as required.

The clay of which the bricks are made is of even texture and unusual hardness when burnt; in fact, it closely resembles the hard tile pottery of the Roman period. When tested recently, the mean breaking weight at centre on a bearing of 20 inches exceeded 15 cwt. per brick. This would give a safe distributed load of nearly 6 cwt. per square foot.

The objection, stated previously, to floors consisting of two layers of different materials is overcome in this case by using concrete composed of the same burnt clay as the bricks; thus, although in two layers, the materials of each are identical.

The cost of this floor is 6*s.* 9*d.* per square yard, and the weight is $29\frac{1}{2}$ lbs. per square foot, including joists and concrete.

If it were possible to expose all the floors described, together with a brick arch, simultaneously to a fire burning for several hours at a temperature of 2500° Fahrenheit, the author is of opinion that the only floor which would be found "fireproof" would be the brick arch, although the others are undoubtedly capable of giving great resistance to fire, retarding its action by confinement, and, in this way, giving greater chances of extinction.

The conclusion arrived at finally is, that with the exception of the brick arch, there is no such thing as a "fireproof" floor, and that it would be more correct to describe all these floors as "fire-resisting."

The following works have been consulted in compiling this paper:—'Proceedings of the Institution of Civil Engineers,' 'Proceedings of the Royal Institute of British Architects,' Rivington's 'Building Construction,' and Captain Shaw's 'Fire Surveys.'

The author desires to express his thanks to the makers of the different floors for the manner in which they have all assisted him with the fullest information and illustrations of their respective systems.

TABLE GIVING APPROXIMATELY THE RELATIVE COST, WEIGHT, AND SAFE LOAD OF A FLOOR 12 FEET SPAN IN THE DIFFERENT SYSTEMS.

	Cost per Square Yard.		Weight per Square Foot.		Safe Load per Square Foot.	Length of Arch.	Span.
	Exclusive of Joists.	Inclusive of Joists.	Exclusive of Joists.	Inclusive of Joists.			
Arch Construction—							
Dennett	6*s.* 9*d.*	9*s.* 3*d.*	50 lbs.	54 lbs.	2 cwt.	12 feet	10 feet
Doulton	6*s.* 6*d.*	9*s.*	30 „	34 „	2 „	12 „	6 „
Wilkinson	6*s.*	7*s.* 6*d.*	50 „	52 „	2 „	12 „	10 „
Flat Construction—						Bearing	
Dawnay	..	7*s.*	..	40 „	2 „	12 feet	Immaterial
Gardner	..	7*s.*	..	46 „	2 „	12 „	„
Homan and Rodgers	..	7*s.*	..	35 „	2 „	12 „	„
Lindsay	..	7*s.*	..	44 „	2 „	12 „	„
	No joists required.						
Evans and Swain..	10*s.* 6*d.*		20*s.*		7 „	12 „	„

DISCUSSION.

On the motion of the PRESIDENT, a vote of thanks to Mr. Lawford for his paper, was unanimously passed.

Mr. A. T. WALMISLEY said their best thanks were due to Mr. Lawford for bringing before them a subject of such importance. To write an impartial paper upon a matter in which there were so many different inventions was no easy task. Every maker naturally considered his own system the best. The various systems were well illustrated by the diagrams, and the table of cost, weights, and sizes showed their comparative advantages at one view. In his opinion, the less that iron was introduced into a fireproof floor the better. When the Alexandra Palace was burned the iron girders twisted up like

corkscrews. Iron was a very treacherous material in a fire, and when introduced into a building it should always be well protected by fire-resisting material. Many of the floors that had been introduced had been laid before the public as arched forms, but he thought that a better description would be flat floors with a curved soffit underneath. The curve was not in general sufficient to allow the floor to partake of the nature of an arch. In Homan and Rodgers' system the brickwork shown in the diagram appeared to be put in simply as a support to the concrete until it was set. As such, no doubt the brickwork was useful and well introduced. He agreed with the conclusion of the author that a brick arch was the only absolutely fire-resisting floor. The system of Mr. Wm. Lindsay, Jun., of Westminster, compared favourably, as regarded weight, cost, and strength, with other systems. A floor would probably never be called upon to sustain a load of more than 2 cwt. to the square foot, unless it was required to carry heavy machinery. The author had no doubt described the best floors, though there were many others which he had not dealt with. The firm with which the President was connected had brought out a floor which had been used in many places. He considered the 12-foot bearing which had been adopted by the author in his table was certainly sufficient, and would not be exceeded under ordinary circumstances. He was pleased with the interlaced system of flooring referred to, as Figs. 2, 3, and 4. In many cases they were limited in headway. Where they were obliged to have the rolled joists shallow, say perhaps one-thirtieth ($\frac{1}{30}$) of the span, it was a good plan to interlace them, as in Lindsay's system. No rolled joists or girders should be put in with a less depth than from one twenty-fifth to one-thirtieth of the effective span.

Mr. Henry Lovegrove said it had been his lot to see fireproof floors of various constructions after fires had taken place. He agreed that a good-sized wooden beam would last very much longer than iron under the action of fire. He had observed that fact after a fire in a country infirmary, where both iron and wood had been made use of. Captain Shaw had recommended woodwork covered with plaster. Looking at the diagrams he (Mr. Lovegrove) observed that some of the floors were laid quite close to the concrete. He should like to know from some practical man whether it was possible to do that. He had on several occasions used Dawnay's system of fireproof floors, and had found it extremely cheap, and that it had always given thorough satisfaction. The system recently patented by Mr. Mark Fawcett appeared to be a very good one; it appeared to be a step in the right direction. A great

deal was said about public buildings being fireproof, but he thought that the real point to be kept in mind was that in places of entertainment there should be such a construction of fire-resisting material as would give the audience time to escape before there could be danger of suffocation.

Mr. J. GOODMAN said that about a year and a half ago he was engaged in carrying out some experiments on fireproof materials, and obtained a great deal of information which he regarded as of considerable practical value. He believed that no floor, of whatever construction, was absolutely fireproof. One point upon which the author had not touched was the imbedding of wire netting or wirework of some kind into the concrete, more especially close to the under surface to which the ceiling was attached. This was an important point which came out very clearly in the test to which he had referred. Under a very fierce fire concrete began to peel off in flakes of from $\frac{1}{2}$ inch to 1 inch in thickness. It was well known that Captain Shaw would not allow his men to go into a building which had concrete floors unless he knew that wire netting was imbedded in the concrete. In one of the tests referred to, two joists covered with concrete and having wire of $\frac{1}{4}$ inch in diameter twisted closely round and coming close to the outer surface of the concrete, were exposed to the fire for four or five hours without showing any sign of giving way, but after a time the concrete began to flake off, and ultimately the joists gave way, and although the temperature was considerably more than 2000° Fahr., these joists resisted for seven hours fifty-one minutes. The fire was made in a furnace specially built for the occasion and supplied with an air blast. It was fiercer than would be met with in an ordinary accidental fire. Observations were made as to the temperature at the abutment and the deflection of the joists. Each one was about 12 feet long and was loaded with 30 cwts. of pig-iron in the centre. At short intervals of about a quarter of an hour the deflection and temperature of the joists and the temperature of the flames just between them were taken. Amongst the floors tested were ordinary wooden ones, almost equivalent to that adopted by Evans and Swain. He also tested a Doulton-Peto brick floor and one of Jones' silicate cotton, covered with Hitchens's salamander plaster, and with uncovered joists. The wooden joists stood about an hour and a half before giving way, but the iron joists gave way in eleven minutes. The relative fire-resisting qualities of the different systems, taking unprotected iron joists as the unit, were—iron joists covered with concrete and wire netting 42·8, and when covered with silicate cotton and salamander compound was practically the same, viz. 42·9. The

unprotected iron joists expanded at the rate of 3·6 inches per hour, joists covered with silicate cotton 0·072 inches, and joists covered with concrete 0·094 inches. Thus the silicate cotton came out slightly the best. In another test the joists covered with silicate cotton did not give way after seven-and-a-half hours' exposure to firing. Taking the concrete covered joists as the unit, the relative fire resistance of the Doulton-Peto tiles was 2·45, and the silicate cotton 4·3. The great drawback of many of the tile systems was that as soon as the joists got hot the joints between them opened and allowed the flames to get through; but when a flexible material was used, such as silicate cotton or asbestos, the joists could expand and deflect without causing damage to the covering. The serious drawback, however, to silicate cotton was that, although it would stand heat splendidly, as soon as a stream of water from the fire-hose played on it with full force it got washed away like so much snow. His own ideal of a perfectly fireproof floor was some such system as Lindsay's or Fawcett's, viz. bricks combined with silicate cotton or asbestos. The material used in this system also made the floors sound-proof. Both Lindsay's bricks and Fawcett's bricks would stand heavy loads remarkably well when steady, but would probably fail under impact.

Mr. Max Clarke said that he had known a concrete floor 40 feet long and 14 feet wide and about 8 inches thick, in which there was no iron whatever, to have been in existence for 15 years, and which had withstood a considerable amount of hard usage. As to the system in use in America, he believed that it was formed with rather a soft brick which could be cut with a saw, and into which nails could be driven. This material he had seen at the American Exhibition, Earl's Court. Some time ago he had occasion to inquire the cost of a floor for a 25-foot span. Probably none of the tables of cost which had been exhibited by the author, would apply to a floor of that width. Several of the diagrams showed wooden fillets more or less embedded in the concrete, and the floors nailed down upon them, but he thought that it would be almost impossible to ventilate a floor of such construction. Again, if the wooden fillets were embedded in the concrete, they would absorb moisture from the concrete and probably soon become rotten. Should it be necessary to lay a floor above the ordinary concrete, some material, such as Wright's porous bricks or fixing blocks, should be embedded in the concrete and the floor fixed upon that material; but such a system as shown by Mr. Bennett, of fitting the floor down tightly with mastic or asphalt, would be still preferable. The diagrams of Messrs. Doulton's system did not show any floors on the fireproof arching. If a

floor of wide span *without woodwork* was required, the space above the bricks would have to be filled up with concrete or some other material, which would perhaps weigh 20 lbs. or 30 lbs. per foot super, and he wished to know whether any of that weight was included in the 34 lbs. which had been mentioned. One advantage in Mr. Mark Fawcett's system seemed to be, that in a floor of wide span with hollow tubes the weight of the filling concrete would be very slight as compared with any of the other systems. It would be interesting to know what claim Lindsay's system had to be called *fire*proof, considering that the iron troughs were left exposed on the underside, and why the concrete was filled in on the tops of the troughs in the way which had been described. He believed that the system described as Dawnay's was used very generally. He should like to emphasise the extreme importance of having the concrete made of good materials, and would be glad to know whether the 2 cwt. which had been stated as the safe load per foot for one of the floors, included the 54 lbs. due to the weight of the material of the floor itself. He should also like to ask whether the author had had any experience of the sudden impact of, say, half a ton weight upon one of the narrow 6-foot bays. He thought that, above all others, the preference should be given to the solid wooden floor described as "Evans & Swain's." After the fire of the theatre at Exeter he saw a baulk of timber which had stood the whole of the fire and was still able to act as a support to the mass of brickwork above. It had got burned chiefly round a hole made in its centre, through which an iron bolt passed. If large timbers were used in buildings, their being pierced by holes should be avoided and iron straps and bolts in connection with them should be avoided as much as possible.

Mr. F. E. Duckham said that four or five years ago he had to design warehouses for the Millwall Dock Company to hold 100,000 quarters of corn—requiring seven acres of floor space—and after mature consideration he decided to make the floors of 4-inch deal with iron tongues and without joists. The deals were laid on wooden girders about 10 feet apart from centre to centre. Wooden uprights were used as far as possible and in other places iron columns were employed. To ascertain the probable effect of conflagration on such an arrangement, a portion of flooring of similar construction was built in a field and tested in the following manner. A fire made with tar barrels and other inflammable materials, took three hours and a quarter to break through the floor, and then only penetrated at one or two places where there were gaps at the ends of the iron tongues. A floor of this construction not only had great fire-resisting pro-

perties, but it had the further advantage of doing away with joists. Hence there was additional head-room, and the inconvenience and nuisance occasioned by spiders' webs, &c. was considerably reduced. The greater value of wood as a fire-resisting material when compared with iron was at about the same date demonstrated at a fire at Messrs. Fenner's Oil-mills at Millwall. A portion of the building was erected about 30 years ago, and was constructed of brick walls with timber beams and timber supports. Another portion, erected more recently and intended to be thoroughly fireproof, had iron beams and cast-iron pillars. The whole building got into a state of very fierce conflagation, and the next morning he found the wooden beams and supports in the old part of the building quite intact, being charred only for a depth of an inch or so. The other portion had been entirely wrecked; the iron beams and the roof trusses were twisted into most fantastic forms and the cast-iron columns were burned down like so many tallow candles in a draught. He wished to add to the foregoing remarks that the floor at Millwall Docks referred to by him, cost 5*s.* per yard for the floor itself, and 9*s.* per yard including girders.

Mr. J. W. Wilson, Jun., said it must be acknowledged that the subject had been brought forward by the author in a perfectly impartial manner. The subject formed a good illustration of the way in which the profession of the Engineer and that of the Architect frequently overlapped one another. With reference to the Evans & Swain floor, he had been recently told by a well-known practical man that among other places it was being used in the improvements in Westminster Hall, and that his experience led him to be in favour of it, as large masses of timber took a long time to burn; also, that in the system in question the timbers, instead of being put flush along the bottom, were sometimes put alternately a little up and a little down for the sake of ventilation. He should like to ask the author whether this was so, and also whether flitching was ever used in connection with that floor. Of course flitching would introduce the element of iron, which was understood to be an objectionable material when subjected to fire; but possibly its advantages in this connection might outweigh the disadvantages as the iron would be pretty well protected from the heat. He should also like to ask, in the case of damp or wet penetrating to the ironwork of any of the floors mentioned, whether there was any arrangement by which it could be drained off. It could hardly be expected that they would be able to put up floors which would resist a long-continued application of intense heat, therefore the point for them to determine was which floor would resist fire for the longest time. In the

case of Homan's fireproof floor it appeared that the concrete hardly depended upon the strength of the small portions of brick interposed above the lower flange of the girder—inasmuch as that they would be in compression downwards, and he should have thought that such a strain would not be an insuperable objection.

Mr. E. A. B. CROCKETT said that with reference to the Evans & Swain floor there was one point which he should like to have cleared up. The author had said that he had experimented upon a floor very similar to Evans & Swain's, but "somewhat similar" might be quite different. His (Mr. Crockett's) opinion was, that theirs was the best floor which they could possibly have. It could be made either in large or in small spans, but of course in the case of a large warehouse there must be intermediate supports, and he had not heard from anybody how it was proposed to protect these supports. What Mr. Duckham had said with reference to the construction of the floor at Millwall Docks was very true. He (Mr. Crockett) firmly believed that the only real fireproof construction was brick supports and brick arches, and that the next best thing was a solid wood floor with well-protected supports. If brick supports could be used, all the better, but if there was not room for brick let oak be used or iron protected with terra cotta.

Mr. D. P. RODGERS said that the firm which he represented had carried out to a very large extent the floor shown by the diagram (Figs. 8 and 9), and they had not found any undue vibration as had been suggested by the author. The joints of the bricks were first well grouted with Portland cement and sand, which united with the concrete and became one homogeneous mass. One object was to do away with the cost of centering. In nine cases out of ten the question of fireproof construction turned upon that of cost. It had been truly said that none of the systems were absolutely fireproof, their yielding was only a question of time. As to the system of his form, which was shown in the diagram (Figs. 10 and 11), it had been suggested that the nibs would break off. In practice he would not admit the possibility of this occurring, as the bricks were only intended in the first instance as a support to the concrete; when the concrete had once become set the brick and the concrete formed one mass having a bearing on the joists, so that the whole of the concrete would have to be crushed before the brick would break; therefore this system gave all the well-understood advantages of a solid concrete floor. In such a floor the beam increased in strength by something like 40 or 50 per cent. as compared with the unsupported beam. His firm could now manufacture the large hog-back bricks at a price which would permit of

floors of 12-feet span, or even more, being made at a cost of 6*s.* 6*d.* In the longer spans the economy in price was even greater than in the shorter ones. As to dry rot, he had known during the last eighteen years several instances of it in cases where the fillets were embedded in the concrete, but he had never known an instance of it where the fillet was simply laid upon the concrete and spiked down to it. Reference had been made to the fire at the Grand Theatre. Two or three days after that event he visited the ruins and found that the whole of the timber portion of the structure had been destroyed, but a piece of concrete floor in the first tier above the pit remained, so that he was able to walk upon it with safety. Perhaps he might be allowed to state that the systems which had been imputed to Messrs. Measures were the inventions of Mr. Julius Homan, and at one time worked by Messrs. W. T. Phillips.

Mr. DOULTON said that the author had mentioned thrust in connection with his (the speaker's) floor. There was naturally a certain amount of thrust, because the floor was built on the principle of the arch. The different sections, for example, shown on the diagrams, viz. No. 1 and No. 2, were intended for different spans. It was thought safer for a floor with 8-feet spans to have the rise as shown in No. 1, than to have the section perfectly flat, although, from experiments which he had himself made, he had found that a flat arch was capable of sustaining weight, even with 8-feet spans. It was found that the thrust was overcome as a rule by the weight of the superincumbent brickwork. At Whiteley's there were four or five storeys, and in none of those storeys was any tie-beam or tie-rod put, except where required for the roof. Some of the floors sustained heavy weights, having to support machinery. Any sort of floor could be erected with his sections. It could be filled in with concrete if desirable, or wood joists could be used and a wooden floor nailed thereon. Ventilation is readily obtained by breaking into any of the hollow spaces formed in the blocks. These air chambers are regarded as a great advantage. To show how good a non-conductor this floor proves to be, in an instance where it has been adopted at a Turkish bath, the effect has been to diminish the temperature of a room, so as to preserve it at about 70° F., although the temperature of the room below is kept constantly at 300° F. As to coke breeze, he should say that it was rather a conductor of heat than a non-conductor, and he had heard of instances where, having been used for hearths, it was found necessary to have it removed, because the fire communicated so much heat to the adjacent timber as to prove dangerous. With reference to Mr. Goodman's experiments with his (Mr. Doulton's) floor, he had previously expressed his regret that he was not aware

at the time that the experiments were about to be made, for though Mr. Goodman intimates that the result was good, he would have suggested such a method of fixing as would have proved the floor to possess far more fire-resisting properties than had been shown. Mr. Goodman states that one of the chief essentials was to prevent the fire getting between the joints, and that if that could be done, the Doulton floor would come next to the brick arch in fire-resisting properties. This alleged want might be easily met by using a fire-resisting mortar. Mr. Clarke had not stated whether the concrete to which he referred had been subjected to fire only, or whether it had undergone a sudden reduction of temperature by the application of water. Mr. Clarke had asked whether the 30 lbs. to the foot super in the Doulton floor included the concrete above. Certainly it did not; it included just what was shown in the diagram. The floor above was optional. He believed that architects in America did not like concrete floors, as they considered them extremely dangerous, but sections similar to those shown in his diagrams had no doubt been previously used in America.

Mr. A. D. Dawnay said that his floor was so simple that it spoke for itself. It contained the least possible amount of iron, and that was wholly covered by the concrete, and thereby protected from the action of the flames. He did not think dry rot could possibly get into the wood covering or finish. He had seen several floors opened out after having lain upon his concrete floors for twenty years, and the woodwork was found to be perfectly sound. One of the speakers had made a remark which almost pointed to a floor of his (Mr. Dawnay's) as having given way, but nothing of the kind had ever happened throughout his experience of more than twenty-five years. [The speaker referred to immediately disclaimed any reference to Mr. Dawnay's design, and stated that it was not his firm that had been alluded to.]

Mr. W. H. Lindsay, referring to a remark which had been made as to the strength of his floor, said that on one occasion about half a ton weight was dropped upon the floor from a height of about 7 feet without causing the floor any injury. Again, it had been remarked that a floor of such construction could not be fireproof. He thought, however, that it might very fairly be called fire-resisting, and when it was provided with a good floor underneath, it was as fireproof as any other. Its real strength was its enormous bearing power.

Mr. Mark Fawcett said that about three years ago, when in Rome, he visited the Baths of Caracalla, and picked up some pieces of Roman scoriæ or volcanic ash, which had been used for concrete. That was a very light material, and it struck him that if it could be got to this country it would make the very

best material for the aggregate of concrete floors. It would be lighter than pumice or breeze concrete, and it would resist fire better. It would not burn at all, but as it was porous, and heat would penetrate through a porous material more quickly than through a solid one, this was the only objection to its use. With regard to his (Mr. Fawcett's) floor, the author had stated the cost to be 8*s.* 6*d.* per yard super. The price which he had given to Mr. Lawford for the tubes fixed and concreted over was 5*s.* 6*d.*, and that was an outside price. He could erect the complete floor at as low as 7*s.* per yard. In the tests which were made of the tubes, they were not arranged (excepting his fireclay tube) as they would be used in actual work. The other tests made, both with his tubes and with those of Mr. Lindsay, Junr., were carried out by supporting the tubes at the bottom, and not on their actual bearing, which was in a slot, and he had discovered that this latter was undoubtedly the weakest part, as his fireclay tube had broken there when loaded in the centre. None of the tests, excepting those of his fireclay tubes, were of any practical value, and he had only tested the others in that manner for the purpose of comparing their strength with Mr. Lindsay's. One important point had been omitted, viz. that his (Mr. Fawcett's) tubes had not to carry any weight at all after the concrete was set. The weight was actually taken by the concrete, and the concrete bore directly on the iron; it had a totally independent bearing on the iron. Only within the last two days he had knocked out two of the tubes from a floor which had been constructed for about a month, and loaded the concrete with upwards of a ton on 4 superficial feet. This weight had no effect at all on the concrete. This showed that the concrete was strong enough in itself to bear the whole of the weight, the function of the tube being to protect the iron by means of the lower flange of the tube passing under it, to reduce the dead weight and save centering. The tubes and the concrete together would actually carry about 2 tons per foot super. Of course the iron would not be so strong as that, unless the span was very short, so that the strength of the floor was the strength of the iron. But the real question was not what dead weight the floor would carry, but what shock it would resist. He had put the side or lateral flanges on the tube, so that the concrete would get a direct and independent bearing on the iron and take the shock of anything falling upon the floor. He considered this to be a very important point. The fireclay he used was the very best to be got in England. It contained over 80 per cent. of silica and would withstand 3000 degrees of heat. He recently submitted a piece of this fireclay to a rough test in a blacksmith's forge, viz. by subjecting it to a blast for

about twenty minutes, without fusing it or causing it to run, and then while hot it was thrown into a tub of water, without any bad effect being produced. The red stuff would fuse at about 2000 degrees, and if a broken section was thrown red hot into water, it would crack up, because the broken edge allowed the water to get into the material, whereas the unbroken section had a skin on it which would prevent the water from so doing. He had provided a continuous and communicating air space between the iron and the fireclay, and by putting air-bricks in the wall, he got a current of cold air between the two. The diagram (Figs. 16 and 17), as exhibited by Mr. Lawford, did not correctly represent the arrangement. The flat bottom dropped down about half an inch below the iron joists, and each tube communicated with every other one. The tubes were laid diagonally, the ends being cut off at right angles to the diagonal line. When the iron joists were fixed, the tubes could be got in with great facility and despatch, and in this way they fitted perfectly, whereas with a square end, considerable play would be required, and therefore the iron would not be properly encased.

Mr. A. W. Rammage described a fireproof floor which had been devised by him. The system consisted mainly of blocks of concrete placed between iron or steel corrugations and then filled in with loose concrete, the blocks doing away with the necessity for centering, and providing a key for ceilings, the loose filling and blocks being thoroughly homogeneous; when set it was a perfectly fire-resisting floor. The blocks were primarily designed to protect the iron or steel corrugations from the action of fire, they being absolutely imbedded, and not even the flanges showing, as in other systems. Pipes can be easily laid along the corrugations. The corrugation, by its special form, gives nearly half as much strength again as the rolled joist of equal weight, and a rigidity over wide spans not obtainable in rolled joists.

Mr. Robbins asked Mr. Fawcett how long it was since his tubes had been brought out.

Mr. Mark Fawcett said that the floor had been patented twelve months.

Mr. E. Robbins said that Mr. Lawford in his paper spoke of certain cements as German cements; they were not, however, German originally. Mr. Young, of Middlesbro', had used the slag with limes and cements for many years with great advantage. The success of the Germans in the use of that material had depended entirely upon the fineness of the material made by the pulverizer, the merit of which is minutely described in the speaker's previous patents. The same method of finely

pulverising was introduced by him (Mr. Robbins) in 1873, and now the Germans were adopting the English mode of manufacture and calling it theirs. In speaking of Hitchens' patent Mr. Lawford referred to gypsum. He (Mr. Robbins) wished to distinguish between gypsum and plaster-of-Paris, although plaster-of-Paris was burnt gypsum. The material used by Hitchens, and as described in his patent, was plaster-of-Paris. Mr. Hitchens took out his patent for plaster-of-Paris and silicate cotton (which lost all cohesion by heat) in April 1886. He Mr. Robbins) exhibited the same thing and in a better form in the March previously, and he spoke of it then at the Architects' Meeting in the Agricultural Hall as existing in his patent and examples of 1883 and 1884. At the present time he used crude cotton, in a coarse or fine condition, mixed with burnt silica, such as silicate cotton, or potter's flint, which were his more recent patented improvements; mixed also with about 5 per cent., more or less, of chalk lime or hydraulic lime. It was well known to potters that clays which contained lime were the most refractory of materials that were known to exist. Carbonate of lime was more fireproof than the best fire-brick, and consequently Gilchrist, the potter, lined his furnaces with that material, thereby showing his acquaintance with the fact that clay, silica, and gypsum possessed the best fireproof qualities when properly used.

Mr. LAWFORD made the following communication in reply, viz.:—

That the span of 12 feet, to which Mr. Max Clarke had alluded, was taken simply as a test span for the purpose of comparing the different floors under uniform conditions, and he believed that all the floors described could be made up to spans of 30 feet without involving the use of either main girders or intermediate supports, but that the thickness of the concrete and the depth of the joist would, of course, have to be increased proportionately.

The weight given in the Table for the Doulton-Peto floor did not include any filling above the blocks, as any material from concrete to sawdust could be used for this purpose.

The Table of safe loads on the different floors was exclusive of the weight of the floors themselves.

He regretted that he had no personal experience of the sudden impact of heavy weights on the different constructions, but both Mr. W. H. Lindsay and Mr. Fawcett mentioned instances of the occurrence in which no damage was sustained by the floor.

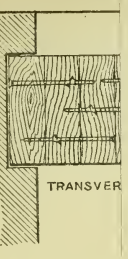
The solid joist floor (Evans and Swain's) was usually made with all the joists flush on both surfaces, but in a few instances

the alternate joists had been raised to allow for ventilation in the manner described by Mr. J. W. Wilson, Jun. He believed that flitching had not been used in conection with this floor, although iron tongues had been made use of, as mentioned by Mr. Duckham.

Alluding to Mr. Wilson's remarks as to drainage, so far as he was aware, provision was only made for draining concrete and iron floors when they were used in stables, in which case the concrete was laid to proper falls and with channels, the latter being kept as far from the ironwork of the floor as possible.

Mr. Fawcett, in his remarks, pointed out a feature which had been unintentionally overlooked in the description of his floor, namely, that the concrete bore directly on the lower flange of the joist, and thus relieved the tubes of the load to a considerable extent. He was glad to take this opportunity of rectifying the omission.

Replying generally to the discussion, it appeared from the observations made by the different speakers that, where iron was used for fireproof construction, it must be covered with a protecting material capable of giving great resistance to fire, and for this purpose brick and terra-cotta were both preferable to concrete. It was also evident that the majority of the speakers were decidedly in favour of timber construction, both for floors and supports, in preference to composite floors involving the use of iron or steel joists. He certainly took this view himself, and considered that the greater cost of timber construction was amply compensated for by the additional security afforded thereby.



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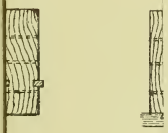

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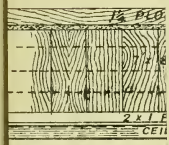

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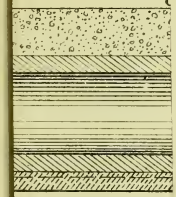

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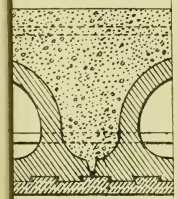

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Fig. 1.
FIREPROOF PLASTER PUGGING.

Fig. 2
SECTION FOR BOARDED FLOOR WITH WOOD SLEEPERS EMBEDDED.

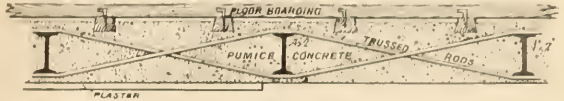


Fig. 3.
SECTION FOR MOSAIC, TILE, CEMENT, OR ASPHALTE FINISH

Fig. 4.

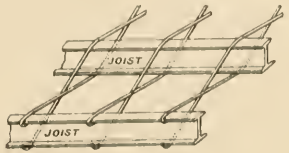


Fig. 5.
SECTION OF ORDINARY WAREHOUSE FLOOR.

Fig. 6.
SECTION OF FLOOR WITH ORDINARY CEILING.

Fig. 7.
SECTION OF 8 IN. FLOORING

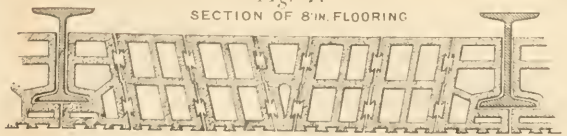


Fig. 8.
LONGITUDINAL SECTION

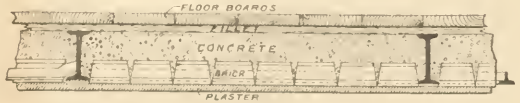


Fig. 9.
TRANSVERSE SECTION.

Fig. 10.
LONGITUDINAL SECTION.

Fig. 11.
TRANSVERSE SECTION

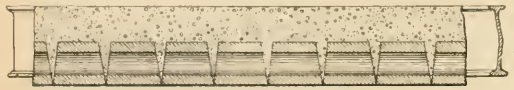


Fig. 12.

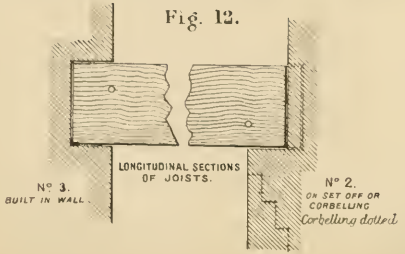


Fig. 13.

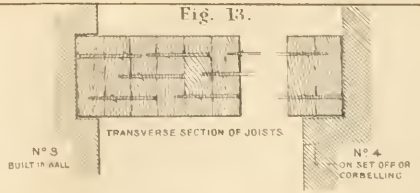
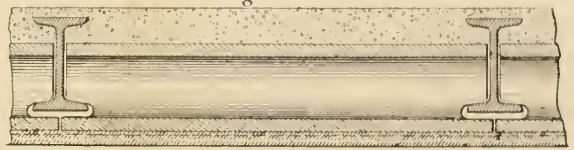


Fig 14.

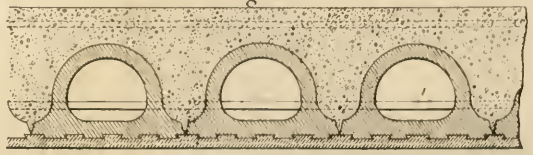
Fig. 15.

Fig. 16.



LONGITUDINAL SECTION.
Showing the bearing of the tubular lintel on the lower flange of the R.I.J. also the air space and allowance for expansion.

Fig. 17.



TRANSVERSE SECTION.
Showing the bearing for the concrete on the R.I.J. and the air space; also the dovetail key for the plaster.

Fig. 18.

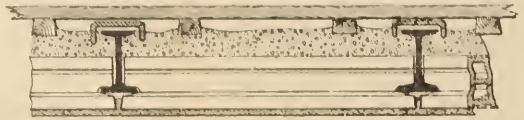
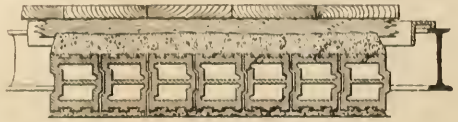


Fig. 19.



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JONATHAN R. BAILLIE, PRESIDENT, IN THE CHAIR.

RECENT DEVELOPMENTS IN HIGH EXPLOSIVES.

By Perry F. Nursey, Past President.

Introductory.

Although the subject of explosive compounds may to some appear to stand somewhat outside the range of engineering discussion, a moment's reflection will show that this is by no means the case. Without the aid of modern blasting agents of the more intensely powerful class known as high explosives, some of the greatest engineering works of modern times could not have been effectually carried out. Witness the blasting operations at the entrance to East River, New York, where, in the autumn of 1885, 150 tons, or 300,000 lb. of nitro-glycerine, and chlorate of potash compounds were exploded simultaneously in removing Flood Rock at Hell Gate. Without their aid many mining operations could not be conducted with profit, and in some cases workings would have to be abandoned altogether, owing to the character of the ground being such that gunpowder will not touch it.

One of the first requirements in carrying out mining, quarrying, tunnelling, and other similar engineering operations, is the dislodgment of large masses of rock and other similar natural formations, as quickly, safely, and cheaply as possible. For many years the only explosive agent at command was gunpowder, and in many cases the process of blasting was slow and unsatisfactory, particularly in either wet or very hard ground. In course of time, however, chemistry came to the rescue of the miner, and gave him the means of blasting in the wettest ground and in the hardest geological formations, where previously he was, in the one case, unable to "keep his powder dry," and, in the other, to get any ground at all, especially in vertical holes. Modern chemistry has produced a long list of explosives of a far more powerful character than gunpowder,

some of which have found their way largely into practice for mining and general blasting purposes. The tendency of invention in this direction has been to produce an explosive compound which shall develop a greater power than gunpowder, and which shall consequently perform an equal or greater amount of work with a lesser quantity of explosive, and, above all, which shall not be liable to explosion except under the actual conditions of work. Of the numerous attempts which have been made to supersede gunpowder for blasting purposes, only a few have succeeded, owing to the delicately sensitive nature of the ingredients in some of the compounds, or to some other equally objectionable feature. The unsuccessful attempts form a long list, which it is not necessary here to consider, the object of the author being to record and consider the successful rather than the unsuccessful results of scientific research in this direction of late years.

Earlier Explosives.

Upon two previous occasions the author has had the honour of bringing the subject of explosive compounds before the Society, and he conceives that the important part they play in many engineering operations and in mining industries throughout the world, and not less the marked advances made in their development during the past few years, justifies—perhaps demands—a further consideration of the matter. Upon the first occasion, namely, in February 1869, he read a paper upon "Explosive Compounds for Engineering Purposes," in which he reviewed the whole question down to that time. In that paper he noticed gunpowder in its several varieties and the attempt made by Colonel Riley, and subsequently by Mr. Gale, to render gunpowder non-explosive and explosive at will, by enveloping the grains in pulverised foreign substances such as ground glass. The various nitrate and chlorate powders, including Horsley's; the gunpaper of Hockstädter (repatented by Reichen in 1866); the white gunpowder of Reveley; Schultze's gun sawdust; and Neumeyer's inexplosive gunpowder, were described. Nitro-glycerine in its original and dangerous form, as discovered by Sobrero, in 1847, and in its then new and safe condition of dynamite, as modified by Nobel, in 1867, was described, as was also gun-cotton, discovered by Schönbein in 1846, and improved by Abel and others in 1863, and subsequently.

In his second paper, which was read before the society in October 1871, the author described the improvements which

had been made in explosives since his previous communication, and noticed the new blasting agent, lithofracteur, which had then recently been invented by Engels, and which is a species of dynamite of improved character. He pointed out that three distinct modifications of dynamite had been introduced by Abel, Horsley, and Schultze respectively. In each case the object sought was to replace the inert silica in the dynamite by substances which would equally well absorb the nitro-glycerine and yet be explosive in themselves, thus giving a stronger blasting agent as the resulting compound. This is exactly what Engels aimed at, and succeeded in doing, in lithofracteur. Abel granulated gun-cotton, and mixed it with saltpetre and nitro-glycerine, which produced his glyoxilin; Horsley mixed 75 per cent. of his powder, which consisted of chlorate of potash and gall nuts, with 25 per cent. of nitro-glycerine, and Schultze mixed 83 per cent. of his wood powder with 17 per cent. of nitro-glycerine. All these compounds formed very powerful explosives, and both Abel's and Horsley's were tried with some success, but the author is not aware that any of these explosives have come into general use. Lithofracteur was introduced into this country by the author in 1871, and for a while was in use in England. The author has employed it on various occasions for blasting, notably in connection with the Jersey Harbour works, as stated by him in the inaugural address which he had the honour, as President of this Society, to deliver in 1886. Its use, however, has been for some years past confined chiefly to Germany and Australia, in both of which countries it is manufactured.

Rivals of Gunpowder.

Having given the foregoing brief résumé of his previous papers, the author would observe, that of the numerous high explosives described in his first paper he pointed out that the most powerful rivals with which gunpowder would have to contend were nitro-glycerine and gun-cotton. And so it has proved, and in the order of priority in which he placed them; for nitro-glycerine, in one form or other, has hitherto taken the lead as an explosive compound for ordinary blasting purposes, while gun-cotton stands foremost at present for torpedo work, in sunk mines, and in many other naval and military operations of this class. Other explosive compounds have, however, been devised of late, and it would seem as if those of the nitro-glycerine class would be superseded in some directions. We have not, however, yet seen the last of nitro-glycerine.

Dynamite and Lithofracteur.

With a view to the clear understanding of what follows, it appears to the author to be desirable that he should here briefly explain the composition of the two oldest explosives of the nitro-glycerine class already referred to. These are Nobel's dynamite and Engels' lithofracteur, the former of which is composed of 75 per cent. of nitro-glycerine mixed with 25 per cent. of a remarkably absorbent infusorial earth, known as kieselguhr, which is inexplosive and incombustible. This constitutes the dynamite No. 1 of commerce, although there are other qualities made. Lithofracteur contains 55 per cent. of nitro-glycerine, combined with a large additional percentage of other combustible and explosive absorbent media, and but a small proportion only of the incombustible, which is kieselguhr. While possessing all the good qualities of other compounds of its class, lithofracteur is free from their defects, and has moreover advantages which are special to itself alone. One of the chief defects of dynamite is the development of noxious fumes after a shot has been fired. This causes great loss of time in close workings where the men cannot get back to their work until the noxious gases have cleared away. The author considers the development of these fumes to be due to the fact that the explosion of nitro-glycerine is so rapid that the atoms in their divided condition—that is, when mixed with a single mechanical absorbent, such as kieselguhr—have not time to communicate explosion to each other throughout the whole mass of the charge, and a portion is consequently blown out of the bore-hole unconsumed. The energy developed by the explosion of the bulk of the charge acts in such a manner upon the unconsumed portion of the nitro-glycerine as to atomise it, and the atomic vapour mixing with the atmosphere and with the smoke from the fuse, hangs about the face of the work for a considerable time. This it is which causes the fumes so detrimental to health, and so objectionable as enforcing idleness on the part of the miners while waiting for them to clear off. The author is familiar with the fumes of dynamite, and his experience in the use of lithofracteur has satisfied him that, if properly used, no fumes whatever are developed by the explosion of the latter. The reason of this is that while lithofracteur contains a smaller percentage of nitro-glycerine than dynamite, it also contains other ingredients which, while acting as perfect absorbents or carriers, assist also in the explosion, and enable every atom of

the nitro-glycerine to be explodod in the bore-hole, thus preventing any portion being projected into the air in the form of poisonous vapour, as the result of incomplete combustion.

Another drawback possessed by dynamite is that its action, being exceedingly rapid, is more or less locally intensified, producing a smashing, rather than a rending, effect on the rock. It has been found, by means of the chronoscope, that the velocity with which detonation travels along trains of dynamite 30 or 40 feet in length, ranges from 17,000 to 24,000 feet per second. Mr. C. Napier Hake, F.I.C., who possesses a wide knowledge of the action of explosives, informs the author that a dynamite cartridge 1 foot in length occupies only the $\frac{1}{24000}$th part of a second in explosion. At this rate a ton of dynamite cartridges about $\frac{7}{8}$ inch in diameter placed end to end, and measuring one mile in length would be consumed in a quarter of a second by a detonating cartridge at each end. A similar train of dynamite, if simply ignited, would occupy several minutes in its combustion. This rapidity of action is due to the fact that nitro-glycerine is the sole explosive, the development of the power due to its combustion being intensely rapid. Lithofracteur, on the other hand, as already stated, consists of nitro-glycerine combined with a large additional percentage of other combustible and explosive absorbent media, and but a small proportion only of incombustible matter. The result is that the action and reaction of the ingredients of lithofracteur are so nicely balanced as to cause a retardation of the explosion. In other words, it is slower burning than nitro-glycerine, just as large grain gunpowder is slower burning than rifle grain powder, although weight for weight they may both develop the same power, but with a different result. This retardation causes lithofracteur to act with greater rending effect than in the case of other nitro-glycerine compounds, which have a smashing action. With lithofracteur the rock is not merely crushed to powder within a limited area around the bore-hole, but is rent and fissured—lifted, in fact—to a very wide extent, so that at each shot the miner gets much more ground. These remarks, as well as those relating to noxious fumes, also apply to some other high explosives to be presently described. The reason why the author has dwelt somewhat at length upon dynamite and lithofracteur is that they are in the main the prototypes of later developments in high explosives of the nitro-glycerine class.

The Dynamite Case.

The author has stated that lithofracteur was introduced into this country from Germany in 1871, and for a while it was in use here. As soon, however, as the commercial working of the patent was fairly started, the British Dynamite Company, now Nobel's Explosives Company, commenced proceedings in Chancery against Messrs. Krebs for an infringement of Nobel's dynamite patent. The case was heard in June 1877, before Mr. Justice Fry, who gave judgment for the plaintiffs. The defendants carried the case to the Court of Appeal, and in April 1878 the Master of the Rolls and the Lords Justices James and Thesiger, without calling upon the respondents, discharged the order of the Court below, and allowed the appeal with costs. The plaintiff company then appealed to the House of Lords, and on April 7, 1879, the judgment of the Court of Appeal was reversed. By this decision what was known as the nitro-glycerine monopoly was still reserved to Nobel's Explosives Company, and thenceforth for some little time nothing was done by others in this country to develop the manufacture of explosives containing nitro-glycerine. In the United States, however, considerable progress was made in this direction, and several varieties of dynamite were brought out there from time to time.

Nobel's dynamite patent, by the effluxion of time, expired on May 7, 1881. Application was made by Nobel's Explosives Company to the Judicial Committee of the Privy Council in March, 1881, for a prolongation of the patent. The application proved unsuccessful, and upon the expiry of the patent the user of nitro-glycerine became public property, with the result that numerous explosive compounds having nitro-glycerine as their base have since been invented, and have been brought under public notice from time to time. The author has introduced the foregoing particulars relating to the proceedings in Chancery by Nobel's Explosives Company on historical grounds, the cause having attracted considerable attention during its continuance, and for some little time afterwards, as the great "Dynamite Case." It is now probably forgotten by all save the leading actors in it, of whom the author was one, he having been at one time one of the defendants to the suit, and from first to last the technical adviser of Messrs. Krebs, the proprietors of the lithofracteur patent, and for whom, during about ten years, he acted as consulting engineer.

Modern Explosives.

At the present time the list of explosives of one kind or other is far more extensive than many of those who possess a knowledge of the subject would perhaps believe. The author was not aware of its extent until, a few months since, Major J. P. Cundill, R.A., one of her Majesty's Inspectors of Explosives, was good enough to give him a copy of his 'Dictionary of Explosives.' From that useful work the author finds that there are no fewer than 348 kinds of explosives, many of them, however, bearing a very close family likeness to each other. Major Cundill has divided them into eight classes, which the author gives in the following list, adding the number of varieties in each class :—

Class.	Varieties.
I. Gunpowder	.. 16
II. Nitrate mixtures	.. 63
III. Chlorate mixtures	.. 67
IV. Nitro-compounds containing nitro-glycerine ..	.. 82
V. Guncotton and other nitro-compounds	.. 64
VI. Picric powders	.. 11
VII. Sprengel explosives	.. 5
VIII. Miscellaneous explosives, including fulminates ..	.. 40
Total	348

It is hardly necessary to observe that, although the list of explosives given by Major Cundill is very long, that of the explosives in practical use in this country is, comparatively speaking, very short. These may be practically classed under three main heads, viz.—1. Gunpowder in its numerous forms 2. Gun-cotton and other nitro compounds. 3. Dynamite and similar nitro-glycerine compounds.

Available High Explosives.

In dealing with the present subject, the author does not propose to trace the history of high explosives. This, while occupying far too much time, would be of little, if any, practical value. His object is to bring under the notice of the members such high explosives as are, or shortly will be, available for blasting purposes, and are suitable for mining and engineering operations. In doing this he will mainly notice those which he has been professionally engaged in investigating, as well as others at experiments with which he has been present. As far as possible the various explosives will be referred to in the order in which they were brought under the author's notice.

In following this course, he distinctly desires to state that he must not be understood as in any way attempting or intending to fix the date of any one invention, or to indicate priority of patent right. That is a question the discussion of which, for obvious reasons, is not permitted in this Society.

Blasting Gelatine.

Following apparently in the track opened up by Abel with his glyoxilin, already referred to, Nobel, in 1875, produced what is known as blasting gelatine. Whilst Abel used the most explosive form of guncotton as an absorbent for nitro-glycerine, Nobel used a lower product of nitration of cellulose. He employs the so-called soluble or collodion gun-cotton, upon which the nitro-glycerine has a peculiar solvent action. The fibrous substance becomes gelatinised, while the nitro-glycerine, at the same time, becomes fixed. Unlike dynamite, this explosive has the great advantage of being practically unaffected by water. It can therefore, if desirable, be kept under water like wet gun-cotton. It is also less liable to freeze than dynamite, although in the frozen condition it is more liable to explosion from violent concussion than dynamite is. It possesses greater power than dynamite, which is due to an increased proportion of nitro-glycerine and the use of explosive nitro-cotton in place of the inert kieselguhr. The greatest care has to be taken in the manufacture of blasting gelatine, otherwise when in store it is liable to deterioration and even to decomposition. Up to the year 1880, blasting gelatine was only produced upon an experimental scale in this country, although its manufacture on a commercial scale had advanced considerably on the Continent. In time, however, it was placed upon the market in Great Britain, and for a while met with some success. Defects, however, developed themselves in this compound, possibly from want of due care in manufacture, and it was withdrawn, only, however, to be replaced on the market after a time. Blasting gelatine was largely used in the works of the St. Gothard Tunnel.

Gelatine Dynamite and Gelignite.

Gelatine dynamite is an outcome of blasting gelatine, and it occupies a place midway between the latter compound and dynamite. It consists of a thin blasting gelatine mixed with other substances, such as nitro-cotton and charcoal. Gelignite consists of gelatine dynamite mixed with nitrate of potash or

other nitrates. The varieties of these two explosives in practical use, contain nitro-glycerine, nitro-cotton, nitrate of potash, and wood meal. They are similar in appearance to blasting gelatine, and while gelatine dynamite contains about 80 per cent. of explosive, gelignite contains 60 per cent. only. All three varieties are stated to be in regular practical use.

Roburite.

The author now comes to a series of explosives which belongs to what is known as the Sprengel class or type, that is, explosives formed by the admixture of an oxidising with a combustible agent, the constituents themselves being non-explosive. The first of these for notice is roburite, which is a mixture of two substances neither of which separately possesses explosive properties. Roburite was invented by Dr. Carl Roth in 1886, and consists of a mixture of nitrate of ammonium with chlorinated di-nitro-benzole, the resultant being a yellowish powder. It volatilises without explosion or ignition when slowly heated, and burns slowly in the open in small quantities. It requires an extra strong detonator to develop its power, and in this respect is a very safe explosive. In the early part of 1887 a factory was established by a German company for the manufacture of the two component parts of roburite, at Rudersdorf, near Berlin. From thence they are conveyed as ordinary chemicals to Witten-on-the Rhine, where they are mixed and the explosive is prepared for use. In July of the same year the Roburite Explosives Company was formed in England for the manufacture and sale of the blasting agent. A factory has been built at Gathurst, near Wigan, where the manufacture is carried on, and which factory, by the courtesy of the Roburite Company, was recently inspected by the author. The works are divided into two parts, completely separated from each other. In the one the components are made; in the other they are mixed together, and the explosive thus formed is packed in cartridges and stored ready for issue.

The advantages claimed for roburite are:—1. That the two components are perfectly harmless and inert separately, so that they can be stored and transported without any restriction: 2. That even when mixed or ground up together the mixture is safe to handle and use, as neither concussion, friction, nor the application of an ignited or heated body, will cause it to explode; this can only be effected by using a strong detonator. 3. That when detonated, roburite produces neither spark nor flame, and will not, therefore, ignite firedamp nor coal-dust in mines.

Dr. Roth states that this point was decided by the trials of the Imperial German Commission upon Accidents in Mines, and that, in consequence, this explosive is now being introduced into the coal mining regions of Germany, as affording absolute safety to the men employed. 4. That the quantity of noxious gases produced by its explosion is infinitesimal. The report from a mine in Westphalia, with shafts about 1,500 feet deep, states with reference to roburite: "The men are not inconvenienced by the gases, and experience no difficulty whatever in breathing the moment after a shot has been fired, and they resume their labour at once." 5. That roburite is not subject to deterioration through climatic variations of temperature. It should be kept dry, but if it becomes damp, it is stated that its strength can be safely restored by drying.

Roburite has been subjected to searching public tests. In June 1887, a series of experiments was held at Chatham, under the superintendence of officers of the School of Military Engineering, for the purpose of proving its safety and explosive power generally; and in October of the same year the owners of the Monk Bretton and Wharncliffe Silkstone Collieries, in Yorkshire, and of the Silksworth and Bunker's Hill Collieries, in Durham, provided facilities for exhibiting its advantages as a blasting agent for coal mines, which were fully demonstrated.

The author's experience with roburite, although somewhat limited, is very satisfactory. He has seen it used in the Appley Bridge sandstone quarries, near Wigan, where in one case 1½ lb. of black powder would have been used in a 3-foot 9-inch hole. The charge was 8 oz. of roburite, which did its work well, shifting a heavy ledge of rock. In another hole, 3 feet deep, in which ½-lb. of black powder would have been used, the work was excellently done by 3 oz. of roburite, the shot getting the block solid and without shattering, being precisely what the quarrymen wanted. The author also had experience of the use of roburite in the Ince Coal and Cannel Company's 4-foot Wigan seam, the pit being 425 yards deep. In this company's pits compressed gunpowder was formerly used, but it has now been entirely superseded by roburite in all their workings, its use having extended over some ten months. The shots in the coal did their work most thoroughly without shattering, 3 oz. of roburite in one case getting about 2 tons of coal, and 5 oz. in another case bringing down 5 tons. Some 8 oz. breaking-up shots fired in the roof cut out the metal in one instance for a length of 7 feet 6 inches, with a width of 7 feet by 2 feet thick, and in another for a length of 6 feet, with a width of 7 feet and a thickness of 2 feet 4 inches. Although the author hurried back to the face of the workings, he could detect but the faintest

trace of fumes, although he was keenly seeking for them. There, moreover, was no flame, for roburite is practically flameless when exploded in confinement, the gases evolved by its combustion being of such a nature as to quench any initial flame there may be. The experience of Mr. Charles Cockson, the manager of the Ince Colliery, is that roburite and black powder stand in the relation of about three to one; that is to say, that where, as a rule, 12 oz. of compressed gunpowder were formerly used, 4 oz. of roburite are now employed with equally good results and at about the same cost.

The value of roburite has been also appreciated by the Wigan Coal and Iron Company, who now use it exclusively in their pits. They, however, did not adopt it without making some searching tests in order to ascertain whether or not it would ignite an inflammable mixture in ordinary shot-firing. The roburite was fired with a very light tamping in a highly inflammable mixture of gas and air, but without in any case exploding the gas. Besides being used at the collieries already alluded to, roburite is also employed in a number of other pits in the Wigan district, as well as in Durham and the midland counties. Its rending power—as contradistinguished from shattering—and its practical flamelessness, make it a very useful explosive in coal mining.

Securite.

Another explosive of the same class as roburite is securite, which consists of a mixture of di-nitro-benzole and nitrate of ammonium. It is the invention of Herr Schoeneweg, and has been in use in Germany for over two years. It is now being manufactured in this country by the Flameless Explosives Company, at Denaby, Yorkshire. By the addition of an organic salt, securite is rendered flameless, and therefore forms a fitting explosive for collieries. Although flameless, it does emit a spark on explosion; but this spark is powerless for harm, inasmuch as it does not possess sufficient energy to explode inflammable gases and coal dust. Moreover, the slight spark that is produced is instantly damped down by the action of the organic salt. It is stated that the addition of this salt to securite does not decrease, but rather adds to its power, for it increases the volume of gas, and at the same time the explosive force of the charge is raised. The flameless character given to securite by the organic salt can also be imparted to ordinary dynamite by the same means. The flameless securite is a finely granulated yellow powder, which possesses the further recommendation of being non-hygroscopic. The author was present at some ex-

periments made with securite in February 1888, when, in the first place, a piece of dynamite was lighted with a match, when it burned quietly away. A piece of the same dynamite rendered flameless by admixture with some of the organic salt was then submitted to a similar flame, but it could not be ignited. A similar attempt to ignite the flameless securite was made, but without success. A red-hot poker was then used, but this only caused a browning of the powder and the destruction of such portions of it as came in contact with the poker. No flame whatever was produced, the powder only disappearing in the form of smoke, a hissing sound accompanying the conversion of the solid into vapour. A 2-oz. cartridge of ordinary dynamite was then laid on the ground and exploded by a detonator, a considerable flash being produced upon explosion. A 2-oz. cartridge of flameless dynamite, which consisted of 50 per cent. of dynamite, and 50 per cent. of organic salt, was then similarly exploded, but without any flame being developed. A similar cartridge of flameless securite was now exploded in the same way, and with exactly the same result. This experiment was repeated with corresponding success. In order to test these explosives under conditions somewhat approaching to those of mining, some 18-inch lengths of $1\frac{3}{4}$-inch wrought iron tubes had been sunk into a bank of earth. In one of these was placed 2 oz. of flameless dynamite, composed, as before, of 50 per cent. of dynamite and 50 per cent. of the organic salt. On being exploded, no flame was visible, but the pipe was smashed, and the earth was well opened around it. Another tube was charged with a 2-oz. cartridge of flameless securite, but the fuse proved faulty, and blew out, without exploding the detonator, the charge remaining intact. As there was not another tube available, and as it would have taken some time to remove the tamping and draw the charge, the experiment could not be repeated. Sufficient, however, was done to demonstrate the safety and flamelessness of the new securite, so far as a sight test went, and to show that, other things being equal, safety in coal mining might be assured by its use.

The flameless character of securite having been called in question, the author was nominated by an independent authority to act as referee in settling the point as between the Flameless Explosives Company, and those who disputed the flamelessness of securite. The tests took place in May 1888, when the company was represented by their engineer, Mr. Ernest Spon; the parties making the allegations being also represented by an engineer of experience in the use of explosives. The tests under the author's supervision were made with the view of ascertaining whether or not flameless securite was really flameless upon

explosion, and to this end the securite was exploded in a mixture of atmospheric air and common coal gas contained in a wrought-iron cylinder. This firing cylinder was connected with a gas holder, an apparatus for measuring the gas supplied to the firing cylinder being mounted on the tubing between the two. The object was to form mixtures of gas and air in certain known and definite proportions. These were, in the first instance, 1 part gas to 14 of air by measure, and afterwards 1 part gas to 7 of air, forming the most highly explosive gaseous mixture. The explosives tested were gunpowder, securite, flameless securite, and dynamite, the charges being fired by electricity. Sixteen experiments in all were made, which were set out in detail in the author's report to the company, but it will be sufficient for the present purpose if he generalises the results, which he has the permission of the company to do. The various charges were exploded, both with and without the addition of gas to the air in the cylinder, in order that the comparative effects of the explosions might be noted, and that there should be no mistake as to the results if and when the gas was exploded. A charge of gunpowder fired in the gaseous mixture exploded the gas, but a charge of flameless securite, fired under similar conditions, failed to do so, the test being repeated with a similar result. These charges were placed in a hole bored in a block of wood to imitate a bore hole, but it being considered that too much protection was afforded to the flameless securite, thus favouring it somewhat, it was decided to place the cartridges in earthen vessels and surround the explosive with coal dust. This was something beyond an approximation to firing a shot in a coal seam; it was far beyond it, and in the author's opinion constituted in itself a crucial test, the cartridge being surrounded by loose coal dust, with the top of the cartridge case open, and fired in a highly explosive gaseous mixture. Charges of securite fired under these conditions exploded the gas, but charges of flameless securite failed to do so, although repeatedly tried with the proportion of gas increased from one-fifteenth to one-eighth. In the case of dynamite, a cartridge was rendered flameless by being placed within a cartridge case containing some of the quenching salts. It was fired under similar conditions as to coal dust and gas as were the other explosives, but in the result the gas was not fired. The author's opinion is that flameless securite proved itself to be flameless on explosion, and that its safety as a blasting agent in fiery mines was fully demonstrated by the searching tests to which it was successfully submitted, and which opinion was unreservedly accepted.

Two months later, namely, in July 1888, a second series of experiments was carried out with flameless securite by Mr. C.

E. Rhodes, the manager of the Aldwarke Colliery, Rotherham. The object with which Mr. Rhodes' tests were carried out were, of course, similar to those in the previous case—namely, to test the safety of flameless securite. The apparatus with which his experiments were made was of a less extemporised character than that used in the author's trials. It was, in fact, the apparatus with which Mr. Rhodes has carried out so many safety lamp tests. It consists of an arrangement for providing a highly explosive mixture of purified coal-gas and air, travelling at a velocity of about 6 feet per second, through a chamber 11 feet 6 inches long by 3 feet diameter, and capable of containing about 80 cubic feet of the explosive mixture. The charges were fired in a large iron block, with holes in the side of it $2\frac{7}{8}$ inches deep and $1\frac{1}{2}$ inch square. This block of iron was capable of resisting the force of the charges in it, and as the block when the charge was fired, did not give way, the effect of the explosion was identical with that produced by a blown-out shot in actual mining operations. Tests made with a small amount of tamping on the top of the flameless securite demonstrated that there was no flame nor firing of the explosive mixture. Other tests were conducted in order to, if possible, more severely try the securite, and two shots were fired with the securite after being tamped and then covered with gunpowder; the result being that there was a slight secondary explosion after the firing of the charge of securite, but there was no ignition of the explosive mixture. This secondary explosion may have been caused by the friction arising from the gunpowder being violently thrown against the iron sides of the chamber. The flame observed could hardly be termed an explosion; it more nearly approached that of the ignition of particles of gunpowder separated from one another. The explanation given by Mr. Rhodes as to why the explosive mixture was not fired is that it was displaced by the first explosion of the securite, and that, in consequence of the safety valves being open, the vessel would not get filled again with an explosive mixture prior to the gunpowder (if such was the case) falling back in an ignited condition. Mr. Rhodes does not attach much importance to this experiment, as it was one of such a character as would not arise in practical working, but it was made in order to test the securite as highly as possible.

The next series of tests was made with coal dust and gunpowder, and when placed lightly in the coal dust and surrounded with gunpowder, the securite did undoubtedly fire the gunpowder. To this test Mr. Rhodes does not attach any value, as the securite was in direct contact with the gunpowder, and there was no stemming or tamping. He observes that as

gunpowder is an explosive, and therefore contains its own oxygen, the gases given off by the explosion of the securite, upon the extinguishing properties of which its safety depends, are useless, and of no avail when dealing with it or any other explosive, further than that it is practically mixing one explosive with another, both of which are in all probability fired by the detonator. Experiments were then made in order to test the strength of securite as compared with gelatine dynamite and gunpowder, and these tests, so far as they went, were very satisfactory. Further tests were made with securite in an explosive mixture, and when tamped or stemmed even very slightly, in no case was there any firing of the explosive mixture. Mr. Rhodes has further experimented with securite and has fired it in an explosive mixture, in one case tamped with clay and then covered to the depth of about 4 inches with fine dry coal dust, and in another instance tamped with coal dust in a perfectly fine and dry state, and covered with coal dust as before, and in each case there was not the slightest indication of flame. As the result of his experiments, Mr. Rhodes gives it as his opinion that flameless securite is a most valuable blasting agent, and one which, if properly used, will give an assurance of practically absolute safety in mining work, so far as the communication of flame to the surrounding atmosphere is concerned. Mr. Rhodes also expresses the opinion that flameless securite does not appear to have its useful effect impaired by keeping; that it is not affected by moisture in the atmosphere, that one-third by weight as compared with gunpowder will do the work in coal as effectively as will the latter explosive; and that the fumes given off by securite are neither so strong nor so objectionable as those of gunpowder.

Bellite.

Another explosive belonging to the same group as the two immediately preceding compounds is bellite, which is the invention of Mr. Carl Lamm, a Swedish engineer and chemist. Having developed his invention into practical form, a factory was built near Stockholm, in which the manufacture of bellite was commenced towards the end of 1887. Since that time, owing to its power and safety, it has come well into use in Sweden for general mining purposes, beyond which the Swedish government has adopted it for submarine mines, torpedo work, and for charging shells for artillery purposes. It is also in use in Australia for mining purposes, having made its mark there

very quickly owing to its merits. This explosive is composed of di-nitro-benzole and nitrate of ammonia in certain proportions, the ingredients being mixed together and then subjected to heat. While still warm, the plastic mixture is moulded into cartridges, which, on cooling, are found to be more or less solidified. Bellite owes its practical success to the circumstance that it possesses several special and important attributes, prominent among which are its immunity from explosion by shocks, pressure, friction, or exposure to flame, its comparative incombustibility, and the absence of noxious gases after its explosion. It is also stated to be non-hygroscopic and flameless, and to undergo no change from atmospheric influences. Its great safety lies in the fact that, like its two congeners, it can only be exploded by the aid of a detonating cap.

Upon two occasions the author has been retained by the Bellite Company to assist at and report upon experiments made with their explosive. The first series of trials, which was carried out in November 1888, at Middlesbrough, extended over two days, and were conducted by Mr. Lamm and Mr. C. Napier Hake, F.I.C. The main advantages claimed for bellite, and as to which the author was requested to report, are:—1. That it cannot be exploded by shock or fire, but only by a detonating cap. 2. That it does not shatter like dynamite, but has a more rending action, and is more powerful than the latter explosive. 3. That it does not give off noxious fumes upon explosion; and 4, that it is flameless upon explosion.

The first day's experiments, which took place at the Clarence Works of Messrs. Bell Brothers, were for the purpose of demonstrating the safety, power, and special action of bellite. Its safety under concussion was shown by a weight of 1120 lbs. being dropped from a height of 20 feet on to a bundle of bellite cartridges placed on an iron plate. The result was that the cartridges were simply crushed. Its safety in an explosive flame was demonstrated by surrounding some bellite cartridges with 1 lb. of ordinary gunpowder, and igniting the latter. The explosion of the powder merely broke up and scattered the bellite cartridges about. It is claimed that bellite placed in a $\frac{3}{4}$-inch deal box cannot be exploded by the explosion of a cartridge of the same material on the outside. This was successfully accomplished; but, in the author's opinion, the test, although a crucial one, is not practical. It is one, moreover, in which the line which divides success from failure is a very narrow one. This was shown by the fact that in a similar experiment made with a $\frac{1}{2}$-inch deal box, the contents were exploded. The safety of bellite in a coal fire was demonstrated by placing portions of a cartridge in a smith's forge, and blowing

the forge. The bellite was slowly melted and roasted, neither burning nor exploding.

The power of bellite and its special action relatively to dynamite was shown by detonating charges of the two explosives on $\frac{3}{8}$-inch boiler plates. The charges were fired in three pairs, the explosives in each pair being of equal weight, and fired under corresponding conditions. The results showed that the work done in the first and second pairs was practically equal, but in the third pair the power developed by the bellite was slightly in excess of that of dynamite. The difference of action between the two explosives, however, was very marked, the plates attacked by dynamite either showing a fracture over a small area, or having a piece blown out, indicating a sharp local action. On the other hand, the plates acted upon by bellite were either more deeply indented than the corresponding dynamite plates, or the fractures extended over a greater area. This is attributable to the somewhat slower action of bellite, the power developed being thus more widely diffused.

The second series of experiments of this class were of a similarly comparative character to the foregoing. They were carried out on 70-lb. steel rails, which were variously fractured or broken through according to the quantity of explosive used. The results confirmed those of the plate experiments, and pointed to the localised action of dynamite as against the more distributed effect of bellite. The concluding experiment of the day consisted in firing a 3-lb. charge of bellite buried 4 feet in the earth. Large quantities of earth were projected to a height of about 100 feet, and a crater 11 feet in diameter and 9 feet deep to the loose bottom was formed. The same weight of gunpowder was exploded under similar conditions, and simply lifted the earth a few feet, leaving a hole 4 feet in diameter and 2 feet deep.

The trials on the second day, in the North Skelton ironstone mines of Messrs. Bolckow and Vaughan, were of a more practical character, the object being to illustrate the use of bellite in actual work. All the shots were fired in close headings underground. In every case the charge of bellite used was half the weight of the charge of compressed gunpowder which would have been employed in the same hole. The work done in all cases compared well with that effected by gunpowder under similar conditions. In every case the author hastened back to the facing directly after a shot had been fired, but in no instance could he detect the slightest trace of noxious fumes. Neither did he experience any ill effect whatever from the results of the explosions, although he was in the workings for

about 4½ hours. No experiments were made in support of the claim of flamelessness of bellite. The author, however, carefully watched the explosions of the bellite and dynamite cartridges during the experiments in the open on the previous day. Upon several occasions he saw flame proceed from dynamite, but he never once saw any flash from bellite. Of course this was only a sight test, and is not conclusive, but as far as ocular demonstration went it was satisfactory. The author's observations enable him to state that the claims advanced for bellite were established by the experiments at Middlesbrough and North Skelton, and were confirmed by the further series of experiments at Chadwell Heath, Essex, in February last, which he attended for the Bellite Company.

Carbo-Dynamite.

The author now comes to the later developments of nitro-glycerine compounds, the first of which for notice is carbo-dynamite. This explosive is of British origin, and is the joint invention of Mr. Walter F. Reid and Mr. W. D. Borland. It is composed of ninety parts by weight of nitro-glycerine absorbed by ten parts of a variety of carbon, the greater porosity of which is indicated by its absorbing power. Nor is the high rate of absorption it possesses its only good mechanical feature; it is extremely retentive, which adds greatly to its value as an explosive agent. It possesses several important advantages over ordinary dynamite, which, as has been stated, consists of 75 per cent. of nitro-glycerine mixed with 25 per cent. of kieselguhr, which latter, being incombustible, cannot add to the force of the explosion, and must be looked upon as an adulterant of the nitro-glycerine, so far as explosive effect is concerned. Carbo-dynamite, on the other hand, not only contains 15 per cent. additional nitro-glycerine, but the absorbent substance, besides acting as a safe carrier for the nitro-glycerine, is itself combustible, and adds to the explosive effect. The new explosive, therefore, contains 100 per cent. of actual explosive substance. Carbo-dynamite, moreover, is not hygroscopic, water apparently having no action upon it. The author has examined some of this compound which had been immersed in water for nearly six weeks, but which had not undergone the slightest change, nor was there any exudation. Some ordinary dynamite, placed in water at the same time as the carbo-dynamite had become dissolved, and the nitro-glycerine was lying at the bottom of the water. This freedom from exudation points to the use of carbo-dynamite in fiery mines. Being

unaffected by water, it may be mixed with it in any required proportion. It is claimed that the volume of steam generated at the moment of explosion not only extinguishes any flame which may be produced, but also adds considerably to the effect of the shot. Another advantage is that the explosion of carbo-dynamite does not result in the production of fumes of a deleterious nature. It is further claimed that the explosive force of carbo-dynamite can be regulated.

In April 1888, the author was present at some experiments, and also some practical trials which were made with carbo-dynamite, at Treherbert, Rhondda Valley, South Wales, at the instance of the Carbo-dynamite Syndicate. In the first experiment a 21-feet length of double-headed 80-lb. steel rail was placed on its side on supports 9 inches high and 12 feet apart, and $1\frac{1}{8}$ oz. of carbo-dynamite was laid on the rail and tamped with clay. The explosion broke the rail in two, cutting out about 9 inches and embedding the fragments in the earth. In the next experiment a 1-inch borehole 13 inches deep was made in a large boulder of tough sandstone weighing about 35 cwt. The hole was charged with 2 oz. of ordinary dynamite and fired, the shot splitting the stone up into one large and several smaller pieces. A similar charge of carbo-dynamite was placed in a borehole in a larger stone of the same character, partly embedded in the earth. The explosion shattered the stone to a much greater extent than in the previous case, and on examination it was found to be a denser rock, but it was stratified, and disruption was therefore rendered more easy, so that the explosive did not have a fair chance.

The more practical trials took place in the heading of a tunnel half a mile from the mouth, the tunnel being in course of construction on the Rhondda and Swansea Bay Railway. The tunnel, which is 2 miles in length, runs through a hard sandstone approaching quartzite in texture, and near the end two holes, each 3 feet 9 inches deep, had been bored. The first was charged with 16 oz. of carbo-dynamite and a primer, and fired. On immediately returning to the spot, not a trace of noxious fumes could be detected in the smoke from the fuse. The second hole was charged with 16 oz. of ordinary dynamite and a primer, and fired, and upon returning to the spot noxious fumes were distinctly discernible in the powder smoke from the fuse. It was, moreover, considered by those in charge of the work that the carbo-dynamite shot got more ground than the ordinary dynamite. Some comparative experiments were afterwards made to demonstrate the superior power of carbo-dynamite over ordinary dynamite. Here two lead cylinders were used, each weighing 40 lbs. and measuring 8 inches high

by 4 inches in diameter, bored with a 1-inch central hole 6 inches deep. In one a quarter of an ounce of carbo-dynamite was placed and tamped with sand, and in the other a similar charge of ordinary dynamite similarly tamped. They were both capped and fused and fired, detonators and miners' safety fuse being used throughout the experiments. On examination it was found that the carbo-dynamite cylinder had a spherical expansion around the region of explosion $5\frac{1}{8}$ inches in external diameter, while the original capacity of the borehole, which was equal to 78 cubic centimetres, had become increased to 590 cubic centimetres. The external diameter of the ordinary dynamite cylinder measured around the spherical portion was $4\frac{3}{4}$ inches, and the internal capacity had become increased from 78 cubic centimetres to 347 cubic centimetres, showing a heavy percentage in favour of carbo-dynamite. This explosive is not yet manufactured in this country, but arrangements have been made to import and store it here for the market. The Home Office authorities have also authorised a modification of carbo-dynamite containing 50 per cent. of nitro-glycerine with potassium nitrate, and cork carbon. This, it is stated, is somewhat stronger than No. 1 dynamite, and can be produced at a lower price. The author has satisfactorily used carbo-dynamite in a blast 400 feet from surface and under a 350 feet head of water. The details of this shot will be given later on.

Von Dahmen's Safety Dynamite.

The latest development in explosives of the nitro-glycerine class is the safety dynamite which has been invented by Baron von Dahmen, and which has a very direct bearing upon the question of safety. Those who are familiar with explosives are well aware that a serious element of danger in the use of ordinary dynamite arises from its liability to freeze and solidify at a comparatively high temperature. This solidification commences somewhere about 40° Fahr., and increases rapidly as the temperature is lowered. In its frozen condition dynamite becomes inert, and cannot be exploded, which renders it useless until thawed. Thawing has therefore to be resorted to, and it is this process which constitutes the danger, and which, in fact, is a very fruitful source of accident. Not but what if thawing be properly carried out—and it can be—it is a perfectly safe process. It consists in placing the frozen dynamite in a covered tin can, which fits into the top of a tin kettle containing warm water, into which the can dips. The arrangement, in fact, is similar to that of a glue-pot, the dynamite being thawed

by the application of a gentle warmth. Every miner or quarry man is, or ought to be, provided with one of these thawing kettles, but, as a matter of fact, miners and quarrymen are notoriously addicted to neglecting its use and to thawing dynamite in their own reprehensible way. This consists in placing the frozen dynamite before a blazing fire, in an oven, or on the heated hob; and the records of dynamite accidents show how persistently some men will follow this baneful practice in spite of the warnings conveyed by accidents of this class to others. Miners and quarrymen are, however, not the only sinners in this respect, for thawing cans are not always provided, and often, when provided, their use is not sufficiently insisted on. The necessity for thawing, however, is entirely overcome in the von Dahmen safety dynamite, which was submitted to the author for trial in January last, and with which, in conjunction with Mr. C. Napier Hake, he carried out some experiments.

This new explosive consists of the ingredients of ordinary dynamite, but to which is added a small proportion of another material. It is this addition which not only prevents the dynamite freezing and becoming inert, but causes it to retain and develop its full vigour when detonated at very low temperatures. The experiments were made comparative with ordinary No. 1 dynamite, in order to ascertain, in the first place, whether the two explosives became solidified at a very low temperature, and, if so, whether they could be exploded with useful effect when under the influence of that temperature. It was further desired to ascertain whether the power of either of the explosives was affected by a greatly reduced temperature. In the first place, equal quantities of dynamite and safety dynamite were exploded at the ordinary atmospheric temperature, neither of them having been refrigerated. As a matter of course, the dynamite exploded readily with a good result as regards strength. The safety dynamite was also readily exploded, and with a better result as regards strength. The next experiments were made with equal quantities of dynamite and safety dynamite, both of which had been submitted to a temperature — 15° to 20° Cent. (— 18° Cent. being equal to zero Fahr. or 32° below freezing-point) for twenty-four hours. At the moment of use each explosive had a temperature of — 15° Cent. The dynamite was frozen so hard that it was impossible to make a hole in it to insert the capped fuse. It was, in fact, as hard as a piece of wood. The cap was, therefore, attached to the side of the bare dynamite, but on firing the charge the cap alone was exploded. A great contrast was presented by the safety dynamite, which at the same temperature remained perfectly soft and plastic. The capped fuse was easily inserted

in it, and it was exploded as readily as though it had never been refrigerated. The dynamic effect was very good, and only to the slightest extent inferior to that obtained with the same explosive in its ordinary condition.

The behaviour of the refrigerated safety dynamite was then compared with that of frozen ordinary dynamite with the capped fuse attached to the side of the dynamite, instead of being within the charge. The capped fuse was therefore attached to the side of a cartridge of refrigerated safety dynamite divested of its paper wrapping. The charge exploded just in the same way as did the cartridge of refrigerated safety dynamite with the capped fuse inserted in it, and with a similar result as regards work done. In order to test whether a charge of refrigerated safety dynamite could be exploded by the explosion of a charge of the same compound when detached from it, two cartridges of refrigerated safety dynamite, divested of the wrapping paper, were placed end to end, with an inch space between them, and one was exploded with a capped fuse, the result being that the second cartridge was also exploded. Safety dynamite has also been subjected to careful examination from a chemical point of view and severe testing by Mr. Hake, who reports the process of manufacture to be a comparatively simple one, and the nitrating process to be apparently more rapid and attended with less risk than the ordinary method of nitration. The results of tests made with ordinary dynamite and safety dynamite, in order to ascertain their relative sensitiveness to concussion, lead to the conclusion that safety dynamite is considerably less sensitive to concussion than ordinary No. 1 dynamite. The same remarks also apply to safety nitro-glycerine and ordinary nitro-glycerine.

Taking the results of the experiments as they stand, the author cannot evade the conclusion that Baron von Dahmen has succeeded in greatly lowering the freezing-point of this useful blasting agent. To put it correctly, he has succeeded in producing an uncongealable dynamite, for as yet its freezing-point has really not been reached, although the endeavour has been made to reach it, but in vain. The safety and usefulness of dynamite are thus greatly enhanced, for, as already observed, it is in thawing dynamite that the great bulk of accidents happen.

Hengstite.

It will be seen that the author has only noticed those high explosives which come more especially under the denomination of blasting agents, those having reference to military and

sporting purposes not having been referred to. His reasons for this were twofold; in the first place he desired to present the subject to the Society of Engineers from an engineering standpoint, and in the second he did not wish to unduly encumber his paper. He is obliged, however, to make one exception to the rule he has hitherto observed, and this exception is admissible, inasmuch as it relates to a new powder, which possesses the double advantage of being useful both for blasting purposes and for arms. This powder is the invention of Mr. C. F. Hengst, and it has straw pulp as a base, the pulp being treated first with acids, and afterwards with alkalies. The resultant is a fine fibrous substance, which is granulated for military and sporting purposes, and compressed for blasting purposes. For this powder the claims are advanced that it is smokeless, flameless, non-fouling, and non-heating. It is also claimed that the recoil and report are less than, and the penetrative power and uniformity equal to those of, black powder, with greatly reduced charges. In February last the author was commissioned to investigate the merits of this powder from a practical point of view, and to ascertain how far the claims made for it could be substantiated. In order to do this he first carried out a series of experiments to test it as a military and sporting powder, and afterwards tried it for blasting purposes. The first experiments were carried out at the testing ranges of Messrs. Cogswell and Harrison, at Harrow. The experiments were made comparative with black powder, and in the trials having reference to military use the Government pattern Martini-Henry rifle and ammunition were used. The charge in the case of the black powder was 85 grains, as against 35 grains of hengstite, all other details remaining the same. Considering that the latter powder was only produced experimentally and in small quantities, the results were very satisfactory. The velocities, which were taken by chronograph, were a little lower and a little less uniform than those of the black powder. A grain or two more powder would probably have set the velocities right, but would hardly have affected the question of uniformity. That must remain for practical manufacture on a large scale. The wonder, perhaps, is that, under the circumstances, the want of uniformity was not greater than it was.

The foregoing remarks apply also to hengstite as tested in relation to sporting purposes. Here the charges were respectively 83 grains of black powder and 33 grains of hengstite, the weight of shot, the gun, and other details being the same in both cases. These rounds were fired from a rest, the recoil being recorded. The recoil was less with hengstite than with the black powder, but the velocity was also less, and the irregulari-

ties were greater, than with black powder, as might be expected from what the author has already stated. The fact, however, remains that, both in the case of the rifle and sporting gun practice, good velocities were obtained with greatly reduced charges of hengstite. In the experiments for penetration with shot, the results followed in about the same ratio as those relating to velocity and recoil in the last case, but they would doubtless have given about the same average as black powder with a slighly increased charge. As regards smokelessness, flamelessness, non-heating, and non-fouling with hengstite, the author found the claims to be practically substantiated. Smoke there was none, only a puff of light vapour (carbonic gas), which rapidly condensed and disappeared from sight. Flame there was none, so far as the eye could detect in a darkened rifle range, only a faint pale blue glow being visible at each discharge. Fouling there was none in the ordinary sense of the word, while a number of rounds fired in rapid succession failed to do more than warm the barrel. An equal number of rounds of black powder similarly fired from the same rifle, cold, heated it considerably. As regards the nature of the report, in every case there was distinctly less noise with hengstite than with black powder. As a practical result hengstite may be said to possess, weight for weight, about 150 per cent. greater strength than gunpowder. Another important point is that it is not liable to be exploded by concussion.

The author's experiments with hengstite as a blasting agent were carried on in the underground workings of the Morgan Gold Mines at Dolgelly. The locality of the shots was the stope on the south lode, the ground being hard, gold-bearing quartz rock. The boreholes were all $1\frac{3}{4}$ inch diameter, with an average depth of 2 feet 4 inches. Blasting gelatine is the explosive used in this mine, and in one hole the charge would have been 8 oz. of that compound. Here a charge of $6\frac{1}{2}$ oz. of hengstite was used, not in the compressed but in the fibrous condition, for there was none in the compressed form available for the purpose. Notwithstanding this disadvantage, the shot brought down a large quantity of rock, and cracked and loosened the face of the working over a large area. It was affirmed by Captain Clemo, the captain of the mine, who charged all the holes himself, that the $6\frac{1}{2}$ oz. of hengstite did more work than would have been accomplished with the 8 oz. of blasting gelatine. In the other cases the charges of hengstite used corresponded in weight with the charges of blasting gelatine which would have been used in the various boreholes. In every instance more work was done, that is, more ground was got, and a greater area of the face was loosened, by hengstite than would have been got

and loosened by blasting gelatine. In order to account for this superiority, the author would point out that the explosion of blasting gelatine is exceedingly rapid, and its effects are therefore of an intensely local and smashing character. In hengstite the explosion is slightly retarded, and its effects are therefore more distributed, the result being a lifting and rending instead of a local smashing action. Although the shots were fired in close workings, the author could detect no noxious fumes whatever on returning to where the shots had been fired. The charges were fired by means of an ordinary naked mining fuse, detonators not being required, which is an advantage both in point of safety and working cost. Although hengstite was tried under manifest disadvantage in being only hand-made, and, in the mining tests, in not being in the proper form for that purpose, the author considers the results most satisfactory.

Tonite.

The last explosive for notice with which the author is acquainted by reason of his having been present at experiments made with it, is tonite. The history of tonite extends back to 1870, in which year Mr. Robert Punshon first carried out some experiments with his gun-cotton, which consisted of ordinary gun-cotton, soaked in a solution of sugar and mixed with nitre, in order to regulate its rapidity of explosion. This explosive was subsequently improved upon, and in April 1870, the author witnessed some experiments with it at Wimbledon, where it was successfully tried in rifle practice. The author is not aware that this explosive ever went beyond experiment in connection with small arms. In time, however, Punshon's gun-cotton was improved into what became known as cotton-powder, the improvements being due to Messrs. Mackie, Faure, & Trench, who mixed gun-cotton with nitrate of baryta. The manufacture of cotton powder was started by the Cotton Powder Company, who constructed works at Faversham, where, in February 1875, the author witnessed some satisfactory experiments with this compound. In time the name of tonite was given to this explosive, which is simply a nitrated gun-cotton, the nitrate usually employed being that of barium. Potentite is another variety of tonite, in which nitrate of potash is used in place of nitrate of baryta. This latter explosive is also manufactured by the Cotton Powder Company at works at Melling, near Liverpool. The author believes that both tonite and potentite are still in use, although a letter written by him to the secretary of the company asking for information has failed to elicit an acknowledgment.

Romite.

In the early part of his paper the author stated his intention of confining himself to a notice of those explosives which he had been professionally engaged upon or had witnessed experiments with. He thinks, however, the paper would hardly be complete without a reference to a few high explosives which have incidentally come under his notice from time to time, but of which he has had no practical experience. The first of these is romite, which is the invention of Herr S. Jöberg, a Swedish engineer, and consists of a mixture of nitrate of ammonia with naphthaline or nitro-naphthaline. When required for use this preparation is mixed with chloride of potash. The advantages claimed are safety in transport and the production of a powerful explosive at the moment of use only. Some comparative experiments made with romite and dynamite in the autumn of last year went to show that romite was only about half as powerful as dynamite. This conclusion, however, the manufacturer of romite, not unnaturally, refused to accept.

Mélinite.

During last year mélinite came prominently into notice in connection with experiments which were made with it by the French government. Its composition is kept secret, but it is believed to be an improvement upon an explosive invented by Mr. Turpin in 1885, and which consists of picric acid combined with other substances. The explosive force of mélinite is stated to be about three times that of gunpowder, and this appears to be confirmed by the results of the French experiments. The author has recently heard that another substance called cresilite is now added to mélinite which is said to materially increase its power and safety in handling, as well as to contribute to its stability. Cresilite is said to be a hard, gummy composition which is melted in copper vessels and poured into the shells which are to be charged with mélinite. The process of charging shells with mélinite—for which purpose it appears to be mainly used—is stated to be a delicate and dangerous operation.

Emmensite.

Emmensite is the invention of Dr. Emmens, and is prepared by dissolving at a moderate temperature an excess of picric acid in nitric acid of a density of from 50° to 60° Beaumé; an operation which can be performed without danger if the

temperature is kept low. On evaporating the liquid afterwards, fine rhombic crystals of a bright yellow colour are first deposited, which are followed by others of a lighter hue, and finally by a precipitate of a light grey colour. The crystals forming this precipitate contain more hydrogen than picric acid, but the oxygen is insufficient for complete combustion. To provide this missing quality, Dr. Emmens employs ammonium nitrate, the mixture being effected by melting together five parts by weight of the above crystals with five parts of ammonium nitrate over a paraffin bath. When completely fused, six parts of picric acid are added and thoroughly incorporated, after which the whole is poured out into moulds. These operations involve no danger if the temperature is kept below 200° C. Thus prepared, emmensite is an amorphous solid of a bright yellow colour, completely odourless, but having a bitter taste. It has a spongy texture, and its specific gravity is 1·7. It is made in several degrees of strength, some of the qualities resembling dynamite, whilst others can be used for firearms. It is but slightly sensitive to shock, and one variety can be heated without exploding.

Graydonite.

Graydonite is the invention of Lieutenant James Weir Graydon, late of the United States Navy, who is the inventor of the dynamite shell bearing his name. Mr. Graydon claims for graydonite absolute freedom from danger in handling and transportation, a destructive power of from 400 to 700 per cent. greater than that of No. 1 dynamite, and suitability for military and naval uses. Particulars of its composition have not been made public.

Practical Work.

Besides the experimental trials and practical work done by the author with some of the explosives described, as stated in connection with them, he has also made a few heavy blasts, a reference to which may prove useful. In the same way the author thinks a notice of some of the more important blasting operations is also desirable in connection with the present subject, and this, notwithstanding that he touched upon these points in his inaugural address in 1886. He has made several heavy blasts with lithofracteur, having several times exploded 50-lb. charges under water, under temporary bridges, and against military defences, in demonstrating its suitability for

subaqueous mines and for other military purposes. At the Quenast Quarries, in Belgium, in 1872, the author, in conjunction with Mr. Engels, brought down in about an hour a heavy masonry road bridge which it was desired to remove, lithofracteur being the explosive used. The heaviest blast effected by the author was with 115 lb. of lithofracteur. This was carried out at the Jersey Harbour works, where Sir John Coode desired to remove, amongst other obstructions, a wall of rock which was standing out from the main rock, but running in a line with its face, there being a space of a few feet between the two. This wall was about 20 feet high, 19 feet long, and 12 feet thick, the foot being exposed for a short time only at low water and the rock being nearly covered at high water ordinary tides, thus affording the advantage of the resistance of a good head of water for tamping. At low tide the author planted the 115-lb. charge in the angle formed by the wall and the main rock, with the capped fuse inserted, which was led up to the top of the rock. At high water, which happened to be at midnight, he rowed out, landed, lighted the fuse, rowed away, and in a short time heard the low rumble of the subaqueous explosion and the tumbling of the water. The next low tide revealed the wall of rock reduced to fragments and lying on the bottom, the explosion having also acted in a downward direction. It was computed by the engineer of the works and the author, that at least 400 tons of rock had been dislodged by the blast. This gave about $3\frac{1}{2}$ tons per lb. of explosive used, which may be taken as a fair average of what it should do on a large scale. The author also did some blasting work for Sir John Coode at the Douglas Harbour works, Isle of Man.

Another subaqueous blast of a very different character from the preceding was carried out by the author in December last year with carbo-dynamite. Messrs. Le Grand and Sutcliff having sunk one of their artesian tube wells nearly 500 feet, without obtaining the anticipated supply of water, consulted the author as to the desirability of exploding a charge about 400 feet down the bore, with the view of opening up the fissures in the chalk. The author advised the blast to be made, and was commissioned to carry it out. The boring is situated on land adjoining the Grand Junction Waterworks Company's works at Ealing, on the border of the Brent Valley, and the bore was put down for the company's engineer, Mr. Alexander Fraser. The bore hole was 470 feet deep from surface and $4\frac{3}{4}$ inches in diameter. It was tubed to a depth of 326 feet, and the water level stood at 50 feet from surface. To avoid injury to the tube, and to get well into the chalk, which

was very hard and compact, the shot was fired at 400 feet from surface, thus giving a head of 350 feet of water over the charge, being equal to a pressure of about 150 lb. per square inch. From his experience of carbo-dynamite the author selected that explosive for his shot—in the details of which he was ably assisted by Mr. Reid. The charge was enclosed in a lead torpedo, and was fired by submarine safety fuse and a detonator. The fuse was timed to burn at the rate of 1 foot per minute, and the author employed 6 feet of fuse. The lowering of the torpedo occupied two minutes, which allowed four minutes for the fuse to burn after the torpedo had reached a state of rest, and before exploding the charge. At the end of $3\frac{1}{2}$ minutes, however, the wire rope to which the torpedo was attached gave a rebound, and the water in the borehole was heard to be in a state of violent agitation, the explosion having taken place. The author attributes the fact of the charge being exploded $2\frac{1}{2}$ minutes before its time to the action of the fuse being accelerated by the heavy head of water over it. He mentions the circumstance as a hint to others always to be well within the limit of safety as regards length of fuse. The blast proved a success so far as the work of chambering the chalk was concerned, as large quantities of débris were subsequently pumped up. The water supply, however, was not sensibly increased, and the conclusion is that the chalk at the point is a hard, solid mass, untraversed by any fissures.

Heavy Gunpowder Blasts.

There are two cases of heavy blasting with gunpowder to which the author may here refer. The first of these was the removal of the Rounddown Cliff at Dover in 1843, in which operation 18,500 lb. or $9\frac{1}{4}$ tons of gunpowder, were disposed in three separate charges which were fired simultaneously by a voltaic battery. The second case was at Holyhead, when the harbour was being made. One of the heaviest blasts there was 12,000 lb. or 6 tons of gunpowder, divided up into several charges and ignited simultaneously by means of a platinum wire heated by a Grove battery. The total quantity of rock stated to have been removed by this blast was 40,000 tons, or 3·33 tons per pound of explosive.

In the autumn of 1879 the author witnessed two heavy blasts with gunpowder at some granite quarries on the western shores of Loch Fyne, near Inverary. The first of these blasts was effected with 3 tons of gunpowder at the Crarae Quarry, which is about 8 miles from Inverary, and the second with 5 tons at

the Furnace Quarry, which is some 2 miles nearer that town. The quarries present extensive faces, and it is mainly the faces which are brought down, the powder being disposed in galleries to the rear of the face and as near as possible to the dividing joints of the rock. The mines were fired by electricity, the 3 tons of powder in the Crarae Quarry bringing down an estimated aggregate of about 60,000 tons of granite and the 5 tons at Furnace about 100,000 tons. This gives in each case 10 tons of rock per pound of powder, but it is to be observed that the conditions of work were comparatively easy, the face only requiring a forward heave to detach and throw it down on to the floor of the quarry below.

Heavy Dynamite Blasts.

In the early part of 1885 a considerable blast was effected with dynamite in a stone quarry at San Francisco. Four galleries were driven each 50 feet into the rock, and were returned at the end at right angles, forming a letter L. The explosive, of which 5½ tons were employed, was placed in the return galleries, the charges being tamped with débris. The four explosions were arranged to occur successively, the first to loosen the rock and make the work of the next easier, and so on with the second and third. It was estimated that the 11,000 lb. of explosive had displaced 35,000 tons of rock, being a little over 3 tons per lb., and thus practically agreeing with the author's experience.

The heaviest blast, however, was that which was successfully accomplished in the autumn of 1885, at the entrance to East River, New York, known as Hell Gate, when 150 tons of nitro-glycerine compounds were exploded simultaneously in removing Flood Rock. Nine years previously, namely in September 1876, the most extensive blasting operation up to that date was successfully accomplished in the demolition of Hallett's Reef at the same place. The area then operated upon was three acres, and the weight of nitro-glycerine preparations (chiefly dynamite) used was about 25 tons, the quantity of rock demolished being estimated at over 63,000 cubic yards. Assuming the rock to weigh 2 tons to the cubic yard (that was the weight of the rock in Jersey), we have 126,000 tons of rock removed by 50,000 lb. of explosive, or rather less than 3 tons per pound. After the removal of Hallett's Reef, operations were carried on at Flood Rock on the opposite side, with a view to its removal, and by this means to render safe the navigation of the channel. On October 11, 1885, this object was successfully accomplished by the aid of over 150 tons of explosives which is six times as

much as was used on Hallett's Reef, and which constitutes the biggest blasting operation on record.

In this case nine acres of rock were honeycombed, and charged with 75,000 lb. of No. 1 dynamite, and 240,000 lb. of rackarock, which is one of the potash class of explosives. The nine acres of rock had been pierced from below with four miles of tunnelling in galleries, the floors of which were from 50 to 64 feet below mean low tide, with walls of from 10 to 24 feet thickness between them and supported by 467 columns of rock, each 15 feet square. In the columns and rock roof of these galleries nearly 14,000 holes of an average depth of 9 feet, had been drilled, and each was charged with a 6-lb. cartridge of rackarock, and a 3-lb. cartridge of dynamite. These were all connected by a battery, so as to be exploded by a single electric spark. The shock of the explosion lasted about 40 seconds, the visible results being the raising of an enormous volume of water to a height of 200 feet into the air. Upon subsiding, it developed a mass of broken rock, from which fire issued for a short time; but in two minutes more everything was quiet. No damage was occasioned to property, although a tremor caused by the explosion was felt at some distance. An examination of the rock showed that the explosion had been completely successful.

Conclusion.

From what the author has stated, it will be seen that there are several high explosives of good repute ready to hand for present use, with others promising their aid in the near future. In selecting an explosive various considerations arise, for no single explosive at the present time appears to be suited to every class of ground. The one, however, which possesses to the greatest extent the important attribute of general adaptability will, as a matter of course—other things being equal—take the lead. It is to this feature of modification to suit varying conditions that manufacturers and inventors are now largely addressing themselves. The leading points for consideration in selecting a blasting agent have reference to the character of the ground to be worked; that is to say, whether it is hard or soft, tough or friable, compact or fissured, damp or dry. And when the selection has been made, the explosive should be carefully tried before it is either adopted or rejected. No hard and fast rule can be laid down in the selection of an explosive, but it may be taken for granted that when a miner gets an explosive that suits his ground as well as his pocket, he will hold on to it very tenaciously. Explosives, like most other mundane things, will be found to be amenable to that immutable law which governs the survival of the fittest.

DISCUSSION.

On the motion of the PRESIDENT, a vote of thanks to Mr. Nursey for his paper was unanimously passed.

General WARDELL said that the author had given a very fair and impartial account of the various explosives which he had described, although no doubt he had a favourite among them in lithofracteur, with which he was at one time so intimately connected. He wished to ask, with reference to two of the compounds which had been mentioned, namely, securite and bellite, whether they were not chemically and practically the same substance. He was informed last year, when attending some important experiments in Belgium, that this was the case. He understood the author to state that the strength of roburite to that of gunpowder was as 3 to 1, and he also gathered that the strength of bellite to gunpowder was as 2 to 1. Attention had been drawn in the paper to the difficulty and danger connected with the use of dynamite and blasting gelatine without great precautions. In some comparative experiments made with blasting gelatine and roburite, in which he took part in the North of England during the very cold weather in the autumn of 1887, they used a cartridge of blasting gelatine, without being at all aware that it was frozen, until it was fired. Of course there was no explosion, but inside the iron chamber fragments of the gelatine cartridge were scattered about. He was then told that the material was very liable to explosion by being trodden upon in its frozen state. With regard to the use of explosives in the future, there were so many claimants that it would be difficult to decide between them, and it was wise to adopt the American advice, "Do not prophesy unless you know." No doubt, as had already been pointed out, they would be used for different objects. There had recently appeared in the 'Journal Officiel' of the French Republic a report made by the Director of Mines to the Minister of Public Works, giving a detailed account of a series of experiments, carried on with that completeness and care for which French scientific men were so celebrated, and in summing up the results of the trials the writer gave it as his opinion that the nitro-glycerine explosives would cease to be used on account of their dangerous nature, and that the explosives of the future for mines would be of the Sprengel type, containing di-nitro-benzole, with a proper proportion of some oxidising agent, such as ammonium nitrate. The author had spoken of the absence of injurious fumes after an explosion produced by such an agent. This agreed with his own personal experience in several deep tunnellings. The carbonic acid gas caused by the explosion of

roburite was not in greater proportion than would be found in the atmosphere of London on a foggy day, and he had never suffered any inconvenience, although he was up at the coal-face a few seconds after the firing of each shot; neither had he seen any sign of flame or spark during the extensive trials alluded to.

Captain HEATHORN said that the point which he had looked at in all explosives, and which he had found of most value, was their durability. How long would they last, and to what extent would they deteriorate? The question of main importance was getting them to store well, or briefly, how were they affected, if at all, by moisture and change of temperature?

Admiral COLOMB wished to confirm the remarks of his friend General Wardell as to the extreme fairness with which the subject had been treated in the paper. His connection with explosives was comparatively recent, but, as far as his experience went, the experiments he had witnessed coincided entirely with the statements made by the author as to certain of the explosives which he had mentioned. He thought that they might rely upon the author having given them a completely authentic account of the different values of those agents.

Mr. WALTER F. REID said that, being connected with one of the explosives, viz. carbo-dynamite, he would make a few observations which might be acceptable. With regard to Hengst's explosive, there was one very curious fact connected with it, viz. that the substance of which it was composed was the absorbent used in the manufacture of a kind of dynamite, "palléine," which was only made in Belgium, and it was the only kind of dynamite which was allowed to be transported upon Belgian railways. As to the freezing of nitro-glycerine, he must say that the freezing-point was a very remarkable thing. It was stated in text-books to be 45° Fahr. Samples of the purest nitro-glycerine that could be obtained had been exposed by him in a stoppered bottle in the open all the winter, and they had not frozen. On the other hand, absolutely pure samples had frozen during the winter, and after the warm weather had set in they still remained solid. The uncertainty of the action of cold on nitro-glycerine compounds was a very remarkable thing. Those compounds which had substances added to the nitro-glycerine to prevent freezing were no exceptions. Some years ago Alfred Nobel made a kind of nitro-glycerine which did not freeze in laboratory experiments, but which, under certain circumstances, froze when made into cartridges. There were several liquids the admixture of which would prevent nitro-glycerine from freezing. The great point in a matter of this kind was the practical test of whether a ton weight of the

substance when made into cartridges, and treated as they generally were treated in practice, would stand the test of rough work. It was a very remarkable fact that, although imperfectly exploded dynamite caused noxious fumes, yet if dynamite was simply burnt in an enclosed place there were no fumes. He had never heard any mention made of that fact. With regard to the velocity of explosions, he had observed that when with a high explosive they diminished, beyond a certain limit, the diameter of the column which they were exploding, the detonation was not transmitted, but would cease. He had found this during some experiments in making an instantaneous fuse. He thought that the transmission of the detonation was due to a certain quality of what he might call vibration. He might illustrate what he meant by saying that a great amount of heat might be obtained without any light at all. The heat produced by a hydrogen flame was greater than that from any other source, yet the light from such a flame was almost imperceptible. The absence of flame in an explosive was no indication whatever that it would not ignite gas. Certain rays of the spectrum had a greater detonating effect on chloride of nitrogen than others. This was remarked in a scientific periodical not long ago. He should be rather doubtful about the stability of any oxalates mixed with nitro compounds. He had used them mixed chiefly with nitro-cellulose in the preparation of E.C. powder, and he found that after being kept at a high temperature in the presence of a considerable amount of moisture, the oxalates were decomposed. Many explosives had been made recently with nitrate of ammonia as a component part. There was no doubt that that substance possessed very great facilities for making explosives when it was dry, but from very considerable experience he believed that neither that body nor nitrate of soda would make a practical explosive. Although giving very satisfactory results when fresh, such compounds effervesced when exposed to atmospheric variations, and the surface became wool-like. Some remarks had been made as to the danger of stepping on cartridges of frozen dynamite. In America nitro-glycerine was transported in the frozen state for safety. Danger was created when the cartridge began to thaw on the outside. As to mélinite, there was some mystery as to what it was, but as a matter of fact he believed that it was nothing more than fused picric acid.

Mr. George Bower said, that he concurred with all the remarks which had been made with regard to the impartiality of the paper. That day week he was at Liège attending some experiments with Hengst's powder as an explosive for small arms. It was tested against Austrian powder, which he believed was

considered to be superior to English powder. With 4 grammes of this powder, in the regulation cartridge, there was a velocity of 478 metres per second, and with 1½ grammes of Hengst's powder there was a velocity of 455. These experiments exactly confirmed those made by Mr. Nursey.

Mr. Claud Monckton said, that he might state, in reply to the first speaker, that flameless securite and bellite were not of the same composition. As to the former, it was absolutely non-hygroscopic. Mr. Rhodes had carried out some trials of flameless securite in some collieries at Rotherham, and had reported it to be of an absolutely satisfactory nature. The railway companies had made arrangements for the transport of it by rail. This tended to show that it was absolutely harmless. It did not give off fumes of such a kind as to prevent the work from going on immediately after an explosion had taken place.

Admiral Colomb said, that what Mr. Reid had remarked with regard to the keeping properties of roburite, coincided with his early experience; but he had recently seen a cartridge exploded, apparently with full power, which had been lying in an open field for the purpose of experiment during the five winter months ending on the 12th March.

Admiral Sir William Houston Stewart begged to express his best thanks to the President and Society for the invitation to be present that evening. He was much struck with the fair and impartial manner in which the author had treated the different explosives in his able and interesting paper. The speaker's practical acquaintance with the subject was so crude and limited that he could contribute nothing of value to the meeting. His attention had been directed at different times to the qualities of dynamites, and during a stay of some time in Canada, he was much impressed with the dangers of dynamite as at present manufactured for the market and used in the construction of railroads in Canada, owing to its extreme sensitiveness to cold and changes of temperature. From what he had recently learned of Van Dahmen's safety dynamite, it appeared to possess valuable qualities, being unaffected by cold, heat, or damp, but he was precluded from going further into the subject.

Mr. Nursey, in reply, said that he felt that the highest compliment which could be paid to his paper was to say that it was impartial. General Wardell was quite right in supposing that he (the author) had a favourite. Lithofracteur was his first love, and he still had a lingering regard for her, although she had long since quitted England. And it happened in this way:—After the dynamite monopoly had ceased to exist, lithofracteur was again imported into this country; but unfortunately the first cargo was acid, and did not pass the severe Government

tests. The trouble was caused by the wells of the factory at Kalk, being contaminated by the waste water from a neighbouring tin plate and galvanizing factory. Some of the lithofracteur which had been affected by this contamination was brought to England and the owners were fined, but the authorities permitted the explosive to be taken back to Germany where it could obtain a ready sale, as the German authorities were not so particular as the English. A subsequent cargo of lithofracteur was bad in another direction, the makers having become more or less careless as soon as they found that they had a comparatively free field. Eventually the works at Kalk were sold to the Rhenish Dynamite Company. General Wardell's question as to the relative strengths of roburite and bellite and gunpowder were answered by the author in his paper, where he had stated that roburite and gunpowder stood in the relation of about 3 to 1 and bellite about 2 to 1. But the figures must not be taken as absolute, as the results would vary according to the nature of the ground in which the explosives were used. General Wardell's question as to frozen dynamite was answered to some extent by Mr. Reid, but he, the author, went a little further. From the variable manner in which a reduced temperature acted upon nitro-glycerine, he thought it probable that some of the particles might be in a crystalline state and practically inert, while others remained liquid and active, so that a sudden blow might cause the explosion of the sensitive, uncongealed atoms of nitro-glycerine. Mr. Downie, a former manager of Nobel's Explosives Company, met with his death through the effects of the explosion of a frozen dynamite cartridge, the explosion being caused by a blow. He would ask to be excused from answering General Wardell's question as to whether securite and bellite were not practically the same. He had stated the composition of those explosives, and had carefully avoided any comparison between them which could give rise to questions of anticipation and infringement of patents, the discussion of which questions was not permitted in the Society. In conclusion, the author invited those present to inspect the specimens which he had on the table, of the principal explosives dealt with in his paper.

June 3rd, 1889.

JONATHAN R. BAILLIE, PRESIDENT, IN THE CHAIR.

ON THE FORCED PERCOLATION OF WATER THROUGH CONCRETE.

BY HENRY FAIJA, M. INST. C.E.

IN March 1888, the author read a paper before the Society on "The effect of Sea Water on Portland Cement." That paper was practically only a description of some experiments which he had made during the year 1887, with the object of determining whether or no certain theories which had been propounded in consequence of the failure of concrete works at Aberdeen, were correct.

There was, however, one point on which the author had omitted to experiment, viz. :—The Effect of the Forced Filtration of Sea Water through Concrete; and in order, therefore, to render his former paper complete, and to settle, once and for all, the effect which sea water may have on a sound and properly used cement under these and all other conditions, the author determined to experiment in this direction, and at the conclusion of the discussion on his previous paper stated that he hoped, on a future occasion, to have the privilege of communicating the result of his experiments to the Society.

Those experiments are now complete, nearly one hundred different experiments having been carried out, which all more or less point to one conclusion; and the author thinks that the results of those experiments, which he has now the honour of laying before the Society, are sufficiently conclusive on the point at issue.

The only experiments which have been previously made in this direction, are those by Mr. Messent in 1887, when prosecuting his inquiries into the cause of the failure of concrete at Aberdeen. The complete description of the means employed in carrying out those experiments, are given in Mr. Messent's Report, dated November 24th, 1887, pages 13 to 16. The general results then obtained, so far as the percolation of the water, the extraction of lime, and deposition of magnesia

are concerned, are confirmed by the author's experiments, and it is only to be regretted that Mr. Messent did not carry them somewhat further, instead of stopping at so early a stage, and further, that whole briquettes were not experimented with, instead of only half briquettes which had already been tested, so that the actual strength of those briquettes though which the water had filtered might have been determined.

The experiments for tensile strength which Mr. Messent carried out, are, in the author's opinion, delusive, inasmuch as the repeated drying to which the briquettes were subjected, in order to admit of their being re-immersed so as to absorb more water, would so seriously affect the cement after being repeated a few times, that the loss of 36·8 per cent. in the strength of the sand briquette, which Mr. Messent attributed to the absorption of sea water, should, in the author's opinion, be more properly assigned to the repeated warmings up to which the briquette had been subjected.

The author would remind the meeting that the deduction which Mr. Messent drew from the results of his experiments, and which he adduced in argument, was "that deterioration takes place only when sea water is repeatedly absorbed (when there must be an intermediate exudation or evaporation), or where there is a forced percolation of sea water." This is an extract from Mr. Messent's letter to the author, which was read at the meeting last year, previous to the discussion of the paper, and in carrying out the experiments, the author has endeavoured to follow these lines, as far as was practically possible.

It might be thought that it would be a comparatively easy matter to carry out these experiments, but several difficulties had to be contended with and overcome before the percolation of the water through the briquettes was brought about successfully. The method eventually adopted was as follows:—Two tanks were erected on the second floor, and pipes leading from them were carried down to the ground floor; each of these pipes being terminated by two branches; it was, therefore, possible to filter water through four briquettes at one time, and the object of having two tanks was that one might be used for sea water and the other for fresh water. To the ends of each of these pipes there was a screw coupling, which fitted on to the clamp holding the briquette. (See Fig. 1.)

The clamps which held the briquettes were as shown in Fig. 2 by which it will be seen that they were easily reversible, so that the water could be passed through the briquette in either direction.

The next difficulty was to make a watertight joint between

the clamp and the briquette, and also to make the sides or walls of the briquette watertight, without materially injuring it. The first material tried was Prout's elastic glue, with which the tyres are fixed on to bicycle wheels; this, however was not successful, for although it rendered the joint and briquette watertight for a short time, it was so elastic that the pressure of water soon forced it into bladders, which eventually burst, and necessitated the briquette being dried and warmed in order that the leak might be repaired. The next medium that suggested itself was ordinary pitch, and this, though it was successful in permanently making the sides of the briquette watertight, was found to be so hard and brittle that in screwing up the clamps the briquette was liable to be damaged; in fact several briquettes were broken in this way. Eventually a combination of these two materials was adopted. The india-rubber glue was placed under the clamp to make the water-tight joint between the clamp and the briquette, and when that was successfully made the briquette was pitched all round.

It was thought that it might be possible to avoid pitching the briquette all over, but the pressure of water was found to be such, that unless a considerable portion of the briquette was carefully pitched, the water, instead of passing through the section of the briquette which was afterwards to be tested, took the nearest course through the edge of the briquette. This would have frustrated the principal object of the experiment, viz. to force the water through that portion of the briquette which was eventually to be tested, besides which the amount of water which would have passed through this minimum thickness of concrete, would have been far greater than that which would pass through the $1\frac{1}{2}$ inch of concrete, forming the thickness of the briquette.

The object in wishing to avoid the pitching as much as possible, was that it was feared that the briquette would be materially damaged by the process; for it must be remembered that the concrete briquette would only be a few days old when the pitching would have to be done, and that before the pitch could be applied, the briquette would have to be dried and warmed. This alone, it might be fairly assumed, would detract to a certain extent from the strength of the cement, and then again, before the briquette could be tested all the pitch would have to be knocked or scraped off. As, however, it was found impossible to do without the pitching, the first point was to determine to what extent this treatment of the briquette detracted from its strength.

Eight briquettes were, therefore, gauged in the proportion of

one of cement to three of sand. These were all taken out of the moulds in twenty-four hours; four of them were placed in water where they remained until they were tested, the other four were left in the air to dry for a few days, and when thought to be sufficiently hard to handle without injury, were slowly and carefully dried near a hot plate; the clamps were then fixed to them and the briquettes pitched, in the manner in which it was determined to carry out the experiment; these were then placed in the same tank with the other four, where they remained until two months had elapsed from the time of gauging. They were then taken out of the water, the clamps removed and the pitch chipped off the four which had been subjected to this treatment, and the whole were tested for tensile strength with the following result:—

PITCHED BRIQUETTES.

No. 1 broke at	340 lbs.		
No. 2 „	380 „	}	Average 382 lbs.
No. 3 „	410 „		
No. 4 „	400 „		

BRIQUETTES TREATED IN THE ORDINARY MANNER.

No. 1 broke at	480 lbs.		
No. 2 „	400 „	}	Average 430 lbs.
No. 3 „	390 „		
No. 4 „	450 „		

From the above there appears to be about 12 per cent. loss of strength, due to the warming and pitching of the briquette while in a comparatively green state, and to the jar given to it in afterwards removing the clamps and pitch.

These preliminaries having been settled, and a few trials made, the experiment proper was commenced; and in order to make it complete, and as far as possible conclusive, it was thought desirable to make each series of experiments consist of ten briquettes, each treated in a different manner, five of them being gauged with sea water, and five with fresh water in the following manner:—

A. Gauged with sea water and placed under a pressure of sea water.
B. Gauged with sea water and placed under a pressure of fresh water.
C. Gauged with sea water and placed in a tank of fresh water, where it remained until tested.
D. Gauged with sea water and placed in a tank of sea water, where it remained until tested.
E. Gauged with sea water and left in air.

F. Gauged with fresh water and placed under a pressure of sea water.
G. Gauged with fresh water and placed under a pressure of fresh water.
H. Gauged with fresh water and placed in a tank of fresh water, where it remained until tested.
I. Gauged with fresh water and placed in a tank of sea water, where it remained until tested.
K. Gauged with fresh water and left in air.

The tables in the appendices and the diagrams are referred to by these letters.

The briquettes in all instances were of 1½-inch square section, and were gauged in the proportion of one part of cement to three parts of sand by weight, the sand being that obtained from Leighton Buzzard, and which is generally used here for making ordinary sand tests of cement, it being sifted so that only that was used which passed through a sieve having 400 holes to the square inch, and was caught on a sieve having 900 holes to the square inch.

The head of water, from the top of the water in the upper tanks to the top surface of the briquette, was in all cases 21 feet, representing a pressure of about 9 lbs. per square inch. The fresh water used for gauging and in the tanks, and for filtration, was the ordinary water as supplied by the Chelsea Waterworks Company in this part of London, and the sea water was obtained fresh each week from Lowestoft through the Great Eastern Railway Company.

The primary matter of investigation was to determine the comparative tensile strength of the several briquettes in series Nos. A to K, but the author thought it would be desirable, while carrying out this experiment, to somewhat elaborate it by measuring the amount of water which filtered through each briquette, and by chemical analysis determining the amount of lime which was abstracted from the cement, as well as the amount of magnesia, alkalies, &c., which was precipitated from the sea water, and which remained in the interstices of the concrete.

The general history of a briquette placed under forced percolation was as follows:—Twenty-four hours after being gauged it was taken out of the moulds and placed on a shelf to dry. When sufficiently hard to handle with but little chance of damage, which would generally be at the expiration of about a week from the time of gauging, it was gradually warmed and thoroughly dried. The clamps were then fixed to it, and it was pitched over; it was then coupled to the end of the pipe, the tap opened, and the water let down on to it. The immediate effect of this was to drive the air out at the ends of the briquette,

which were not pitched, followed by the water, in many instances with considerable force; while sometimes, though the latter was large in quantity, the force would not be so great. In all cases, however, the greatest amount of water passed through the briquette in the first twenty-four hours during which it was under pressure. The amount of water lessened day by day, until at the end of a week, perhaps, only a few ounces came through during the twenty-four hours. The briquette was then taken from the pipe and turned upside down, so that the direction of the percolation through the briquette was reversed, when the same characteristics were generally noticed; viz. the water in the first instance coming through with great force, and the quantity during the first twenty-four hours being comparatively large. The percolation, however, after this first reversal, was generally less than when the briquette was first put under pressure. The filtration was allowed to continue for a few days, when the direction would be again reversed, and this procedure was continued unto such time as no water would pass through the briquette in either direction. The briquette was then removed from the couplings, the clamps taken off, the pitch chipped away, and the whole of that series were placed in the testing machine, and tested for tensile strength, so that the comparative strength of the briquettes treated in the different ways was determined.

Occasionally during the process of filtration in any one direction, the water was turned off and the briquette left to dry for a day or two, or perhaps even longer. This was also sometimes rendered necessary by a larger amount of water passing through a briquette during the twenty-four hours than would be due in the ordinary course; which would suggest that a leak had been sprung in the pitching. In such case the briquette was removed from the couplings, and very carefully and slowly dried for several days; the position of the leak was then ascertained, the pitch chipped off it and made good again.

It will thus be seen, that the experiments on forced percolation were carried out, as far as practicable, on the lines set out at the commencement of the paper, as being the manner in which the cement in a concrete was said to be most damaged.

It may be added that some briquettes were made gauged with four parts of sand to one of cement, but the percolation of water through them was at such a rapid rate, that it was thought the experiments would occupy such a length of time that it would preclude the possibility of carrying out a sufficient number to obtain a fair average within a reasonable limit of time; they were therefore abandoned, and the three of sand to the one of cement adopted.

In all, there were seven series of experiments carried out, with four different cements, gauged in the proportion of three of sand to one of cement, which cements were not in any way selected, beyond that it was assured by previous experiment that they were sound cements, though varying slightly in chemical analysis. The comparatively low tensile strain which the whole of the briquettes carried was due to their not having been rammed too tightly into the moulds, as it would be possible for an expert gauger to render a three to one briquette almost impervious to the percolation of water under a head of 20 feet.

The results obtained from the experiments are given in full in the appendices, together with the chemical analyses of the cements and briquettes; but in order to render them more concise, averages only are given in the following Table X.:—

TABLE X.

Average Tensile Strength.

A broke at	452 lbs.		With the 12 per cent. added,	506 lbs.	
B „	358 „		„	400	„
C „	348 „				
D „	354 „				
E „	392 „				
F „	405 „		„	453	„
G „	372 „		„	416	„
H „	417 „				
I „	388 „				
K „	378 „				

Average Loss of Lime from the Cement due to Percolation.

A	4·036 per cent.	of weight of cement.
B	2·955 „	„
F	4·667 „	„
G	2·381 „	„

Average Amount of Deposition of Foreign Matter (Magnesia, Chlorine, &c., &c.), due to Percolation.

A	4·972 per cent.	to weight of cement.
B	1·628 „	„
F	2·857 „	„
G	0·796 „	„

The average number of days from the time of gauging the briquettes to their being tested was 88; the time being determined by the cessation of all percolation of water through those which were under pressure.

The average amount of water which passed through each briquette was 271 oz.; this amount does not, however, give a very clear indication of what the amount of water which passed through each briquette absolutely was, for whereas as much as 900 oz. was measured to have passed through some, only 2 oz.

seems to have passed through another; these, however, were exceptional cases, the majority ranging from 100 oz. to 300 oz. In the exceptional case of the 2 oz., it may be fairly assumed that the briquette was very solidly made, but although that small amount of water was all that absolutely passed through it, it should be noted that the briquette was always wet.

The author's analyses compare very closely with those made by Mr. Pattinson, and which are given in Mr. Messent's report (Table No. 2, page 31), the only real difference being, that whereas Mr. Pattinson attributes the whole of the ingredients other than sand as belonging to the cement, the author maintains that only a portion of them belong to the cement, the others being due to the foreign matters which have filled up the interstices of the concrete. In this opinion, which the author gave on the matter in the reply to the discussion last year, he was supported by Mr. W. T. Dent, as well as by several other speakers.

This, however, is entering into a discussion as to the exact chemical conditions in which the magnesia, sulphuric acid, &c., are found in a concrete after it has been subjected to a forced filtration, and is a matter which cannot be of great interest to the engineer. The chemistry of the matter is of course of very great importance, and must not be ignored; but it would perhaps be better discussed before other societies whose objects and aims are more closely associated with that science.

To the engineer the great point is whether or no any deterioration takes place in a concrete through the influence of forced percolation of sea water, and it seems clear that no such deterioration does take place. Undoubtedly a certain percentage of lime is dissolved out of the cement, but the amount which can be dissolved must be limited in quantity; in these experiments the quantity of lime abstracted has been determined by the length of time during which the concrete remained porous enough to allow of the percolation of water under a head of 21 feet; of course, as soon as the percolation ceased, no more lime could be abstracted from the cement. It is not anticipated that a concrete would be purposely made sufficiently porous to allow of the percolation of water under ordinary heads for an indefinite period, but supposing for the sake of argument that such a concrete exists, it might still be fairly argued that no more lime could be abstracted from the cement after the interstices of the concrete had received the deposit of lime and magnesia which is found on the surface of all concrete works exposed to the action of the sea; even if it may not be fairly assumed that, taking cement to be a more or less imperfect double silicate of lime and alumina, there would

come a time when the free lime, as it is generally termed, would be dissolved away, and there would remain only the perfect combination of lime, silica, and alumina, which would be practically impervious to the action of running water, except of course by attrition.

This argument is, of course, based on the assumption that the abstraction of the lime component of a cement after it has been gauged is detrimental to its strength and permanency, which is at present only and purely theoretical, no experiments having hitherto been made in this direction. The results of the experiments forming the subject of this paper rather tend to prove that a very large percentage of the lime of a cement may be abstracted from it after gauging, without detriment to its strength, if not even to its advantage.

The principal point, however, to be noticed is that the experiments conclusively prove that the forced percolation of water, whether sea or fresh, through a concrete, does not in any way detract from its strength. In the experiments which the author has made, those briquettes through which the water has been forced show an equal, and in some cases a greater, tensile strength than those which have been treated in the ordinary manner of testing Portland cement; and if the 12 per cent. be added which was found to be the average loss in strength of a briquette due to the process it had to pass through in preparing it for filtration, those through which the water has percolated appear rather to have an increased strength over those treated in the ordinary manner.

These results must be as surprising to everybody as they were to the author; he did not hold with the theory that any deterioration would take place, but he certainly did not expect to find that the cement and the strength of the concrete was actually improved by the intermittent and forced percolation of water through it.

TABLE No. I.

TENSILE STRENGTH OF THE BRIQUETTES AND THEIR AGE WHEN TESTED, TOGETHER WITH THE AMOUNT OF WATER WHICH PERCOLATED THROUGH THOSE UNDER PRESSURE.

Tensile Strength in lbs. Water in oz.		Gauged Sea. Filtered Sea.	Gauged Sea. Filtered Fresh.	Gauged Sea. Placed in Fresh.	Gauged Sea. Placed in Sea.	Gauged Sea. Left in Air.	Gauged Fresh. Filtered Sea.	Gauged Fresh. Filtered Fresh.	Gauged Fresh. Placed in Fresh.	Gauged Fresh. Placed in Sea.	Gauged Fresh. Left in Air.	Age when Tested.
Series		A	B	C	D	E	F	G	H	I	K	
				lbs.	lbs.	lbs.			lbs.	lbs.	lbs.	days.
"α" Cement.	Tensile strength	417 lbs.	439 lbs.	320	375	..	..	320 lbs.	400	410	..	39
	Amount of water percolated	*	*	..	..	..	..	*	..	..	..	..
	Tensile strength	600 lbs.	..	450	420	..	..	..	520	480	580	74
	Amount of water percolated	910 oz.†	..	..	..	..	..	..	..	..	..	..
	Tensile strength	610 lbs.	..	..	..	..	..	..	..	..	..	144
	Amount of water percolated	*	..	..	..	..	..	..	..	..	..	..
	Tensile strength	400 lbs.	..	390	420	480	..	..	490	430	480	142
	Amount of water percolated	193 oz.	..	..	..	..	..	..	..	..	..	..
	Tensile strength	540 lbs.	..	..	..	..	..	..	..	..	310	142
	Amount of water percolated	991 oz.†	..	..	..	..	..	..	..	..	..	..
	Tensile strength	..	..	..	..	..	..	..	..	..	300	142
	Amount of water percolated	..	..	..	..	..	..	..	..	..	..	..
"β" Cement.	Tensile strength	320 lbs.	290 lbs.	370	325	410	380 lbs.	290 lbs.	365	340	330	34
	Amount of water percolated	491 oz.	62 oz.	..	..	..	2 oz.	326 oz.	..	..	..	..
	Tensile strength	280 lbs.	350 lbs.	340	320	280	540 lbs.	500 lbs.	400	370	240	51
	Amount of water percolated	*	137 oz.	..	..	..	122 oz.	163 oz.	..	..	..	..
"γ" Cement.	Tensile strength	350 lbs.	350 lbs.	290	320	..	310 lbs.	340 lbs.	410	325	..	42
	Amount of water percolated	465 oz.	174 oz.	..	..	..	135 oz.	163 oz.	..	..	..	..
"δ" Cement.	Tensile strength	555 lbs.	370 lbs.	280	300	400	390 lbs.	410 lbs.	335	360	405	75
	Amount of water percolated	908 oz.†	*	..	..	..	71 oz.	233 oz.	..	..	..	..
Average tensile strength		452 lbs.	358 lbs.	348	354	392	405 lbs.	372 lbs.	417	388	378	Average days, 88·5
Add 12 per cent.		54 lbs.	42 lbs.	..	..	..	48 lbs.	44 lbs.	..	..	..	
With 12 per cent. added		506 lbs.	400 lbs.	..	..	..	453 lbs.	416 lbs.	..	..	..	
Average amount of water percolated		659 oz.	124 oz.	..	..	..	82 oz.	221 oz.	..	..	Average of the whole, 271 oz.	

* The amount of water measured as having passed through these briquettes was in all cases very large—the greater quantity being due to the leakage of the briquette during the earlier stages of filtration; they are not therefore considered sufficiently accurate to record.

† A portion of the water measured through these is probably due to leakage.

TABLE No. II.

CHEMICAL ANALYSES OF BRIQUETTES COMPOSED OF "*a*" CEMENT, AND THROUGH WHICH WATER HAD BEEN PERCOLATED.

No. of Briquette	1	2	3	4	5	6	7
Index Letter	B	G	A	A	A	A	A
Loss at red heat, &c.	5·200	5·200	5·600	6·000	5·900	6·300	6·700
Silica	3·700	3·930	3·120	2·840	3·420	3·920	3·630
Alumina and Oxide of iron	2·900	3·330	3·480	2·540	2·940	3·140	2·710
Lime	13·300	14·730	14·560	12·740	13·400	13·900	13·410
Magnesia	0·320	0·257	0·883	0·700	0·840	0·640	0·720
Sulphuric acid	0·220	trace	0·699	0·500	0·600	0·520	0·557
Alkalies, &c.	0·296	0·046	0·474	0·568	0·616	0·568	0·590
Sand and Insoluble matter	74·090	72·700	71·460	74·800	72·080	70·620	71·850
	100·026	100·193	100·276	100·688	99·796	99·608	100·167

TABLE No. III.

SHOWING THE AMOUNT OF SAND, CEMENT, AND DEPOSITION IN THE BRIQUETTES COMPOSED OF "*a*" CEMENT, DEDUCED FROM TABLE No. II.

No. of Briquette	1	2	3	4	5	6	7
Index Letter	B	G	A	A	A	A	A
Sand	75·916	73·659	71·012	76·631	74·145	73·154	74·959
Cement and Deposition	24·084	26·341	28·988	23·369	25·855	26·846	25·041

TABLE No. II*.

CHEMICAL ANALYSES OF BRIQUETTES COMPOSED OF "β" CEMENT, AND THROUGH WHICH WATER HAD BEEN PERCOLATED.

No. of Briquette	8	9	10	11	12	13	14	15
Index Letter	A	F	B	G	F	A	G	B
Loss at red heat, &c.	6·700	7·100	6·000	6·800	5·000	5·100	4·000	4·000
Silica	2·820	3·900	3·400	3·400	3·480	3·480	2·800	3·440
Alumina and Oxide of iron	3·260	3·300	3·440	3·350	4·040	3·880	3·880	3·800
Lime	15·240	16·100	15·560	15·200	13·480	13·800	14·640	14·320
Magnesia	0 960	0·580	0·500	0·320	0·535	0·562	0·159	0·275
Sulphuric acid	0·720	0·390	0·510	0·320	0·275	0·362	0·397	0·463
Alkalies, &c.	0·507	0·497	0·141	0·092	0·474	0·428	0·046	0·141
Sand and Insoluble matter	69·720	68·000	70·280	71·300	73·360	72·840	74·040	73·160
	99·927	99·867	99·831	100·782	100·644	100·452	99·962	99·599

TABLE No. III*.

SHOWING THE AMOUNT OF SAND, CEMENT, AND DEPOSITION IN THE BRIQUETTES COMPOSED OF "β" CEMENT, DEDUCED FROM TABLE No. II*.

No. of Briquette	8	9	10	11	12	13	14	15
Index Letter	A	F	B	G	F	A	G	B
Sand	71·450	71·034	71·848	73·003	72·649	72·631	72·718	72·889
Cement and Deposition	28·550	28·966	28·152	26·997	27·351	27·369	27·282	27·111

TABLE No. II**.

CHEMICAL ANALYSES OF BRIQUETTES COMPOSED OF "γ" CEMENT, AND THROUGH WHICH WATER HAS BEEN PERCOLATED.

No. of Briquette	16	17	18	19
Index Letter	G	B	F	A
Loss at red heat, &c.	5·500	5·200	4·350	5·100
Silica	2·340	2·440	3·670	3·640
Alumina and Oxide of iron ..	2·040	2·000	3·440	3·280
Lime	10·100	10·080	15·100	14·840
Magnesia	0·318	0·310	0·609	0·622
Sulphuric acid	0·250	0·310	0·446	0·452
Alkalies, &c.	0·046	0·184	0·610	0·520
Sand and Insoluble matter ..	79·280	79·140	71·770	72·320
	99·874	99·664	99·995	100·774

TABLE No. III**.

SHOWING THE AMOUNT OF SAND, CEMENT, AND DEPOSITION IN THE BRIQUETTES COMPOSED OF "γ" CEMENT, DEDUCED FROM TABLE No. II**.

No. of Briquette	16	17	18	19
Index Letter	G	B	F	A
Sand	81·910	81·880	71·271	72·135
Cement and Deposition	18·090	18·120	28·729	27·865

TABLE No. II***.

Chemical Analyses of Briquettes composed of "δ" Cement, and through which Water has been Percolated.

No. of Briquette	20	21	22	23
Index Letter	A	F	B	G
Loss at red heat, &c.	6·300	3·700	4·500	3·700
Silica	3·220	3·850	3·850	3·800
Alumina and Oxide of iron ..	3·070	3·800	3·500	3·100
Lime	11·600	14·750	13·700	13·600
Magnesia	1·090	0·410	0·390	0·180
Sulphuric acid	0·678	0·390	0·040	0·280
Alkalies, &c.	0·510	0·474	0·184	0·092
Sand and Insoluble matter ..	73·520	72·250	73·300	75·650
	99·988	99·624	99·464	100·402

TABLE No. III***.

Showing the amount of Sand, Cement, and Deposition in the Briquettes composed of "δ" Cement, Deduced from Table No. II***.

No. of Briquette	20	21	22	23
Index Letter	A	F	B	G
Sand	76·303	72·562	74·938	76·677
Cement and Deposition	23·697	27·438	25·062	23·323

TABLE No. IV.

ANALYSES OF THE CEMENT AND DEPOSITION FOUND IN THE BRIQUETTES COMPOSED OF "α" CEMENT, CALCULATED FROM TABLES II. AND III., TOGETHER WITH THE ANALYSIS OF THE ORIGINAL CEMENT "α"; SHOWING ALSO THE AVERAGE LOSS OF LIME, &C., FROM THE CEMENT DUE TO PERCOLATION.

	Cement.							Original Cement, "α."	Average Losses, Calculated to Percentage of the Cement.		
No. of Briquette	1	2	3	4	5	6	7				
Index Letter	B	G	A	A	A	A	A		A	B	G
Silica	25·778	26·665	26·981	24·191	25·649	26·227	24·392	23·747			
Alumina and Oxide of iron	12·910	13·332	13·490	12·096	12·824	13·047	12·196	11·873			
Lime	59·134	58·982	56·452	60·577	58·456	57·751	60·380	61·537	2·821	2·403	2·555
Magnesia	0·843	0·832	0·871	0·875	0·880	0·865	0·875	0·831			
Sulphuric acid	0·977	trace	1·732	1·741	1·749	1·720	1·741	1·652	..	0·675	1·652
Alkalies, &c.	0·361	0·178	0·372	0·375	0·377	0·370	0·375	0·356			
	100·003	99·989	99·898	99·855	99·935	99·980	99·959	99·996			

DEPOSITION.

CALCULATED AS PERCENTAGE TO THE CEMENT.

	1	2	3	4	5	6	7
Magnesia	0·578	0·294	2·433	2·330	2·628	1·620	2·244
Sulphuric acid	..	..	0·932	0·606	0·821	0·423	0·724
Alkalies, &c.	0·949	..	1·393	2·207	2·178	1·904	2·163
	1·527	0·294	4·758	5·143	5·627	3·947	5·131

TABLE No. IV*.

ANALYSES OF THE CEMENT AND DEPOSITION FOUND IN THE BRIQUETTES COMPOSED OF "β" CEMENT, CALCULATED FROM TABLES II* AND III*, TOGETHER WITH THE ANALYSIS OF THE ORIGINAL CEMENT "β"; SHOWING ALSO THE AVERAGE LOSS OF LIME, &c., FROM THE CEMENT DUE TO PERCOLATION.

	Cement.								Original Cement, "β."	Average Losses, Calculated to Percentage of the Cement.			
No. of Briquette ..	8	9	10	11	12	13	14	15					
Index Letter	A	F	B	G	F	A	G	B		A	B	F	G
Silica	23·712	23·085	24·220	24·178	28·975	27·869	26·985	26·971	22·835				
Alumina and Oxide of iron	12·042	12·684	13·308	13·286	15·921	15·314	14·828	14·820	12·544				
Lime	61·849	61·884	60·194	60·325	53·121	54·466	55·970	55·850	62·403	4·245	4·381	4·900	4·255
Magnesia	0·663	0·644	0·637	0·628	0·643	0·642	0·605	0·630	0·624	..	..	..	0·019
Sulphuric acid ..	1·493	1·439	1·426	1·267	1·081	1·429	1·394	1·408	1·393	..	..	0·312	0·126
Alkalies, &c.	0·195	0·190	0·185	0·185	0·189	0·189	0·184	0·186	0·184				
	99·954	99·926	99·970	99·869	99·930	99·909	99·966	99·865	99·983				

DEPOSITION.

CALCULATED AS PERCENTAGE TO THE CEMENT.

	8	9	10	11	12	13	14	15
Magnesia	2·983	1·534	1·269	0·635	1·420	1·539	..	0·438
Sulphuric acid ..	1·310	0·058	0·536	..	..	..	0·120	0·392
Alkalies, &c.	1·717	1·665	0·352	0·148	1·625	1·453	0·001	0·352
	6·010	3·257	2·157	0·783	3·045	2·992	0·121	1·182

TABLE No. IV**.

ANALYSES OF THE CEMENT AND DEPOSITION FOUND IN THE BRIQUETTES COMPOSED OF "γ" CEMENT, CALCULATED FROM TABLES II** AND III**, TOGETHER WITH THE ANALYSIS OF THE ORIGINAL CEMENT "γ"; SHOWING ALSO THE AVERAGE LOSS OF LIME, &C., FROM THE CEMENT DUE TO PERCOLATION.

	Cement.				Original Cement, "γ."	Average Losses, Calculated to Percentage of the Cement.			
No. of Briquette	16	17	18	19					
Index Letter	G	B	F	A		A	B	F	G
Silica	25·543	25·128	27·295	26·833	24·219				
Alumina and Oxide of iron	12·065	11·869	12·894	12·684	11·440				
Lime	59·751	59·820	56·630	57·350	61·320	3·970	1·500	4·690	1·569
Magnesia	0·863	0·868	0·881	0·880	0·855				
Sulphuric acid	1·456	1·464	1·486	1·485	1·442				
Alkalies, &c.	0·273	0·732	0·743	0·742	0·721	..	..	..	0·448
	99·951	99·881	99·929	99·974	99·997				

DEPOSITION.

CALCULATED AS PERCENTAGE TO THE CEMENT.

	16	17	18	19
Magnesia	1·008	0·955	1·361	1·478
Sulphuric acid	0·023	0·368	0·180	0·252
Alkalies, &c.	..	0·349	1·502	1·227
	1·031	1·672	3·043	2·957

TABLE No. IV***.

ANALYSES OF THE CEMENT AND DEPOSITION FOUND IN THE BRIQUETTES COMPOSED OF "δ" CEMENT, CALCULATED FROM TABLES II*** AND III***, TOGETHER WITH THE ANALYSIS OF THE ORIGINAL CEMENT "δ"; SHOWING ALSO THE AVERAGE LOSS OF LIME, &C., FROM THE CEMENT DUE TO PERCOLATION.

	Cement.				Original Cement. "δ"	Average Losses, Calculated to Percentage of the Cement.			
No. of Briquettes	20	21	22	23					
Index Letter	A	F	B	G		A	B	F	G
Silica	25·501	25·154	25·353	23·521	22·447				
Alumina and Oxide of iron	14·914	14·710	14·805	13·758	13·120				
Lime	56·393	57·087	57·962	60·356	61·500	5·107	3·538	4·413	1·144
Magnesia	1·470	1·388	1·374	0·798	1·363				0·565
Sulphuric acid	1·347	1·272	0·168	1·240	1·248		1·080		0·008
Alkalies, &c.	0·345	0·326	0·322	0·322	0·320				
	99·970	99·937	99·984	99·995	99·998				

DEPOSITION.

CALCULATED AS PERCENTAGE TO THE CEMENT.

	20	21	22	23
Magnesia	3·549	0·116	0·276	
Sulphuric acid	1·803	0·308		
Alkalies, &c.	1·980	1·480	0·464	0·088
	7·332	1·904	0·740	0·088

TABLE No. V.

SHOWING THE AVERAGE AMOUNT OF LIME, &c., ABSTRACTED FROM THE CEMENT BY PERCOLATION IN EACH SERIES THROUGHOUT THE WHOLE OF THE EXPERIMENTS, CALCULATED AS PERCENTAGE OF CEMENT.

	A	B	F	G
Lime	4·036	2·955	4·667	2·381
Magnesia	..	..	..	0·292
Sulphuric acid	..	0·877	0·312	0·595
Alkalies, &c.	..	..	..	0·448
Total	4·036	3·832	4·979	3·716

TABLE No. VI.

SHOWING THE AVERAGE AMOUNT OF DEPOSITION IN THE INTERSTICES OF THE CONCRETE DUE TO PERCOLATION, IN EACH SERIES THROUGHOUT THE WHOLE OF THE EXPERIMENT, CALCULATED PROPORTIONATELY TO REPRESENT PERCENTAGE OF CEMENT.

	A	B	F	G
Magnesia	2·311	0·703	1·107	0·645
Sulphuric acid	0·859	0·432	0·182	0·072
Alkalies, &c.	1·802	0·493	1·568	0·079
Total	4·972	1·628	2·857	0·796

DISCUSSION.

Mr. JOSEPH BERNAYS said that the author had given them a paper of very great interest. The question which arose seemed to be, whether he could account at all for the improvement which had taken place in the cement after the filtration of the water. As far as he could see, nothing had been taken from the cement or added to it. Perhaps the greater strength was due to the cement having been made a longer time at the end of the experiment than at the beginning of it. Perhaps the author would explain. Something might be due to the application of warmth in the drying of the cement at starting, which, if he understood the paper correctly, was resorted to only in the case of those briquettes which had ultimately been pitched. It

might be asked why these briquettes had been heated so soon after being made, instead of being left for two months like the remaining ones. It seemed that the pitching was done almost as soon as the briquettes were made, leaving about two months' interval before the experiments took place. Was it a necessity to heat and pitch them at once? Might the pitching not have been left until just before the time when all the experiments were carried out? He supposed that they might take for granted, that cement in its natural state was never quite water-tight. He had found in foundations, the concrete would never get quite dry when surrounded with water. He would like to have an authoritative statement as to whether concrete foundations, and concrete without any waterproof course, could at any time be made absolutely tight against water.

Mr. GEORGE R. STRACHAN said he should like to ask Mr. Faija whether it was a correct inference to draw from Table X. that concrete or cement which had been somewhat roughly handled would in practice lose as much strength as those briquettes which had been pitched. The table to which he had referred appealed to him as a user of cement. The ordinary briquettes which were not pitched bore on an average 430 lbs., and those briquettes which had been covered with pitch a few days and then had the pitch chipped off, lost strength to the extent of 12½ per cent. as compared with the others.

This raised a very serious question, as to whether in practice the cement which they thought had been standing a tensile strain of say 400 lbs., or the concretes of which it was made, did deteriorate to the extent of 12½ per cent. through the rough use of it which took place in practice, and which could not be avoided. If that was the case, perhaps some would think that it would be better to use high proportions of cement for concretes, or cement of a higher tensile strain. Another point occurred to his mind, it was of course difficult to come to a definite conclusion from a table of averages, and it was quite possible to draw erroneous conclusions therefrom. He noticed in the table that the cement experimented upon with the sea water gave the best results. He should like the author's opinion as to whether, in the case of work which would be subjected to the action of sea water, it was best to gauge it with sea water or with a mixture of salt and fresh water. He noticed that sample number eight in the table, which was gauged in fresh water and placed in fresh water, gave the best results of the whole. He wanted to guard against drawing a wrong inference from the table. With reference to the question raised by the last speaker, whether it was possible to make concrete water-tight, he should like to mention that at Carlisle he had an opportunity of examining the baths where

there was no great head of water, only six or seven feet. Those baths were constructed of concrete, and so made that a person could walk behind the walls. The thickness was three feet six inches, and the walls were absolutely water-tight. The engineer accounted for this successful result by the fact that he was very careful in mixing the concrete, and that the ballast with which he made it was exceedingly fine. His own experience with reference to water-tight concrete was that it did not depend so much upon the strength of the cement, or of the proportion of the latter, as upon the character of the added gravel or sand. Supposing that a given concrete would allow water to percolate rapidly, and that the proportion of admixture was six to one, the quantity of percolation would not necessarily be decreased by making the proportion three to one ; whereas, on the other hand, if the ballast was a little rough at three to one, and care was taken to get a little sand in the proportion, then there would be a decrease in the percolation; in other words, it did not so much depend upon the proportion as upon the fineness of the material mixed with the cement.

Mr. W. Y. Dent said that he thought that engineers were greatly indebted to Mr. Faija for his very interesting series of experiments, which he had carried out in a most unexceptionable manner, inasmuch as he seemed to have avoided every possible source of error. He regretted that Mr. Faija had not taken this opportunity of making and testing briquettes made up with distilled water, as this would have afforded the means of ascertaining how much lime and silica was dissolved out of the cement by its solvent action, without any interference from the salts contained in ordinary fresh water. With regard to the question of the tendency of cement to crack after the passage through it of salt water, from the effects produced by the crystallization of sulphate of lime, he thought that the results of the analyses tended to show that this was not probable, inasmuch, as that the amount of sulphuric acid was not greater in the cement after the filtration than it was before. As to the question of the kind of water, he believed that it was generally considered that the use of salt water or of fresh, in making up the briquettes, made no difference in the strength of the cement.

Mr. P. W. Meik said that the only point which he had to criticise, perhaps a little unfavourably, was with reference to Table X. In dealing with cement it was very advisable not to base deductions upon too few experiments. Mr. Faija was perfectly right in having at least ten experiments in most instances, but in Table X. it seemed that he had been content with four experiments only; this was certainly too few.

Cement varied very much, and it was quite possible that the difference between these two tables might simply be more or less accidental. He hoped that Mr. Faija might at some future time have an opportunity of prolonging his experiments, in order that he might obtain a little information for them as to what the result would be with more porous briquettes. Of course in dealing with three to one briquettes they would not have exactly the same circumstances as those which existed in the case of concrete; and it was possible that after a year or two the circumstances might be somewhat changed, with very porous material. With reference to the remarks of a previous speaker, perhaps the reason why the briquettes which had been gauged with sea water showed so much higher a result than the others, was owing to the formation of a silicate of lime within the interstices of the briquette. That suggestion had been made to him by Mr. Michaeles.

Mr. P. O. FRANCIS said that he was not qualified to contribute anything of value to the discussion, but felt glad as a cement manufacturer to have the opportunity of expressing his thanks to Mr. Faija for his valuable paper, and more particularly, perhaps, for the facts brought out therein as to magnesia. This ingredient having found its way into specifications, had given manufacturers some trouble, being in several cases precluded altogether, but owing mainly to Mr. Faija's experiments the limit had now been pretty generally fixed at 2 per cent., a quantity considered harmless if not beneficial in good Portland cement.

Mr. Francis further pointed out that Mr. Faija's paper seemed to establish that the percolation of sea water through cement concrete deposits magnesia, but only in an inert form, and in no way affecting the durability of the concrete.

Mr. F. T. READE said that he thought that it would be useful if Mr. Faija would mention the area of the briquette through which the water percolated, so that they might have some idea of the amount which would pass through a joint. He should be very glad if the author would touch upon the point mentioned by Mr. Bernays, namely, the amount of water which was held by a concrete foundation. It was a new fact to him that a foundation made in Portland cement concrete apparently always permitted the passage of more or less water.

Mr. J. W. WILSON, Jun., said that in the course of the discussion upon the paper which Mr. Faija had read before the Society last year, he had, he feared, been the cause of unintentionally wounding the feelings of some of those present on that occasion, by a remark which he had made ith regard to cement manufacturers. He had pointed out at that meeting

that though manufacturers had conducted many valuable experiments upon cement and concrete, they appeared not to have done so with special reference to the action of sea-water thereon. He had been in the hope of hearing this evening that manufacturers or their representatives had been conducting a series of experiments during the last twelve months on their own account in this direction. He had understood that it was their intention to do so, and he confessed to a feeling of disappointment that no one had come forward now to say how far their experiences concurred or otherwise with those of the author which they had just heard. They owed a debt of gratitude to Mr. Faija. Twelve months ago engineers had been unsettled as to the use of concrete in sea water; they might all feel now that they were not only justified in thus using it, but that by the use of it in sea water the result might be to produce a still better material than that hitherto used.

Mr. Faija, in reply, said, referring to Mr. Bernays' remarks, that it was necessary to warm the briquettes in order that the pitch should adhere to them and make them water-tight. Immediately the briquette was made water-tight, it was put under the pressure of a 21-feet head of water, and it was left two or three months under that pressure with the water filtering through it alternately in each direction, and, when percolation had ceased, it was tested for tensile strength. It was necessary to pitch the briquettes at the earliest moment, in order that they might be put under pressure.

With respect to Table X., Mr. Strachan thought it conclusive, but Mr. Meik did not. There was a great deal in what Mr. Meik said, and he (the author) should not like to affirm positively that there was an absolute loss of 12 per cent. in strength due to the warming and pitching of the briquette. It was, however, only reasonable to admit that the warming of the briquette, when it was only three or four days old, and while it was still "green," to something like 160 or 170 degrees, so that the pitch would adhere to it, must detract somewhat from its strength, for the simple reason that all the moisture was got out of the briquette, and consequently the crystallisation of the cement was arrested before it was perfect. He should consider that the loss of strength was more due to the warming than to the chipping off of the pitch, as the latter was not removed until the briquette was some three months old, when the cement would be properly set and hard, and if the chipping off was done carefully, it should not materially detract from the strength of the briquette. It did not, however, make any difference in the argument deduced from the results obtained in the experiments, as without adding this 12 per

cent. the briquettes through which the water had percolated compared very favourably with those which had been treated in the ordinary manner.

Mr. Strachan had asked a very difficult question, viz. why the A series of briquettes should be the strongest. He (Mr. Faija) could not definitely answer that question. The series in question comprised those briquettes which were gauged with sea-water and through which sea water had percolated, and there was more deposition in them than in any of the other series. He was quite certain that Mr. Dent could better explain the condition and chemical combination of the deposition than he could. It undoubtedly consisted of a combination of lime, magnesia, alkalies, &c., which, being principally basic elements, would probably form a sort of cement of themselves, which filling up the interstices of the concrete, would add to its strength independently of the original matrix used. The tables in the appendix hardly showed the components of the depositions satisfactorily, for though there was a certain percentage of lime in the deposits, the tables suggest that there was none; this is due to the mode of calculation adopted, which simply showed the plus or minus quantity of each ingredient in the deposition from the original cement.

In reply to Mr. Reade, he (Mr. Faija) did not think that the actual area of the surfaces of the briquette which was subjected to the direct water pressure affected the results to any appreciable extent. The area was 1·227 inches, and the thickness of the briquette 1·5 inches; but the water did not only run straight through, but spread throughout the whole briquette, keeping all the surfaces constantly damp, and sometimes even dripping out of the ends of the briquette, which were three inches distant from the centre of the area of direct pressure.

Fig. 1.

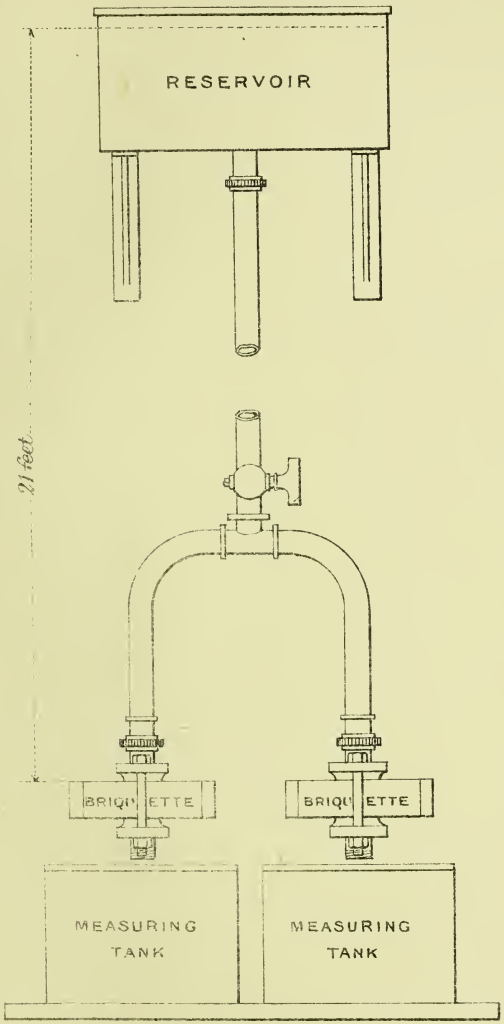
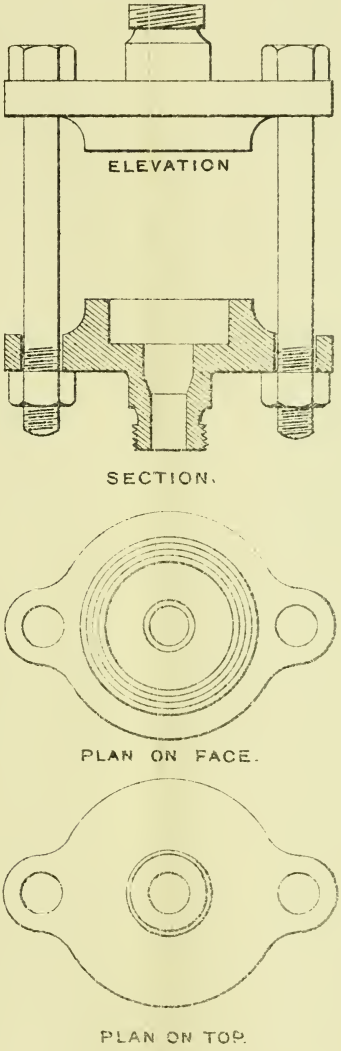


Fig. 2.



E & F.N. Spon, London & New York.

VACATION VISITS.

During the summer and autumn of 1889, the following visits were made:—

On the 27th June, the East London Waterworks at Lea Bridge, Walthamstow, and at Waltham Abbey were visited, the members being received and entertained at luncheon by Mr. W. B. Bryan, M.I.C.E., who accompanied them over the various works.

The East London Waterworks Company was founded in 1808, by the amalgamation of the Shadwell Waterworks Company, dating from 1669, and the West Ham Waterworks Company, dating from 1747, and large reservoirs were constructed at Old Ford.

The intakes since that time have been carried to a point higher up the Lea, at Ponder's End, from whence the water is conveyed to the eight new reservoirs at Walthamstow, covering 236 acres, and having an available capacity of 610 millions of imperial gallons. It passes thence to the filter beds at Lea Bridge, where it flows into the various engine wells at that place and at Old Ford, and is pumped into the district of supply. In addition to the water obtained from the River Lea, the Company has also sunk several wells in the chalk at Waltham Abbey, and gets a further auxiliary supply from the Thames a short distance above Sunbury Lock, from whence it is pumped to the Hanworth filter beds, where also several wells have been sunk, and the water is forced from there to a reservoir near Finsbury Park.

The magnitude of the undertaking may be realised from the fact that about 1,235,000 inhabitants are supplied, and, in addition, the docks on the north side of the River Thames.

It is interesting to note that, amongst the various pumping engines in use at the Old Ford Station, a pair of engines called the Twins, built by Messrs. Boulton and Watt, are still occasionally put in service, and even now, after eighty years' use, are in fair working order, and give far from unsatisfactory results as regards economy. The following is a brief summary of the engine-power per day at the disposition of the Company:—

At Old Ford:—The before-mentioned Twins; the Cornish, with a capacity of 1,500,000 cubic feet; the Wicksteed, 1,700,000 cubic feet; the Hercules, 1,600,000 cubic feet; the Ajax,

1,400,000 cubic feet; all the foregoing being of the Cornish type.

At Lea Bridge are the following engines:—The Victoria, with a capacity of 2,160,000 cubic feet; the Prince, 1,728,000 cubic feet; the Princess, 1,728,000 cubic feet; the Duke, 414,720 cubic feet; the Duchess, 414,720 cubic feet; and a horizontal compound engine, 552,960 cubic feet per day. Besides the above, there are two Hercules turbines and two waterwheels.

At Walthamstow there is an engine similar to the horizontal compound at Lea Bridge, and a Hercules turbine; and there are here eight reservoirs, with a total capacity of 910,000,000 gallons and available capacity of 610,000,000 gallons.

At Chingford Mill there are two Gerard turbines, lifting water from a well and bore-hole 450 feet in depth.

At Woodford, the two reservoirs, each with a capacity of 1,500,000 gallons, are supplied by the engines at Lea Bridge, and the water is pumped from here to the High Beech Reservoir, for supplying the high level district of Loughton, &c., by a pair of horizontal high pressure condensing engines.

At Waltham Abbey, triple expansion engines have been erected for lifting the water from a well sunk in the chalk and forcing it to the High Beech Reservoir; the latter being constructed to hold 2,500,000 gallons, with a water surface of 371 feet above Ordnance datum.

At Finsbury Park is the reservoir already referred to, and known as the Hornsey Wood Reservoir. It contains 5,000,000 gallons, with a water surface 142 feet above Ordnance datum.

At Sunbury, where the auxiliary supply from the Thames is obtained, there are two Bull engines, each capable of lifting 1,600,000 cubic feet per day to Hanworth, where there is an open reservoir of 5,000,000 gallons capacity. From hence the filtered water is pumped by three Cornish engines, with a joint capacity of 23,283,000 cubic feet per day, to the Hornsey Wood Reservoir.

The next visit made by the Society was on the 30th July, to the Outfall Sewage Precipitation Works now in progress at Crossness, where the party was entertained at luncheon by the contractor, Mr. W. Webster, and afterwards conducted over the works by Mr. F. E. Houghton, resident engineer, and Mr. Webster. These works form the outfall into the River Thames for the whole of the sewage of the Metropolis south of the river. The sewage reaches Crossness by an 11 feet 6 inch barrel sewer at a deep level, and is there pumped into existing reservoirs capable of holding 4,000,000 cubic feet of sewage, which is stored for about eight hours per tide, and discharged

at high water. The supplementary Precipitation Works now in progress, the contract for which was recently let to Mr. Webster for the sum of 258,166*l.*, comprise the alteration of the above-mentioned old reservoirs and the construction of others in addition, which, when completed, will altogether provide for 12,000,000 cubic feet of effluent per day. The sewage, after being treated with lime water and iron water, will be thus separated by precipitation into effluent and sludge; the former will be run off into the river almost continuously, and the sludge will be pumped into sludge ships for conveyance and discharge into the German Ocean. The works are designed with a view to the treatment of the sewage for a future population of 2,400,000 persons residing within that area of London lying south of the Thames.

On the 1st October a visit was paid to the Central Station of the London Electric Supply Corporation, at Deptford, where the members were received and entertained at luncheon by the directors, and were afterwards conducted over the works by the representatives of Mr. Sebastian Ziani de Ferranti, the engineer to the Corporation, who has invented, designed, and laid out the whole of the scheme. These premises promise to be one of the most remarkable industrial establishments of the metropolis. The site occupies about four acres on the river-side, with a wharf, on which has been erected a 50-ton steam derrick. The boiler-house is 195 feet long by 70 feet broad, and nearly 100 feet high, constructed to contain boilers of 65,000 horse-power, arranged on two floors, with a coal-store above, the fuel being supplied from the latter to the furnaces by vertical shoots. The present provision is for supplying steam to engines of an aggregate of 13,000 horse-power. There are two engine-houses in course of construction, each 195 feet in length, 66 feet in breadth, and about 85 feet high. In the first engine-house a pair of Corliss engines of 3000 horse-power will be erected to actuate two Ferranti dynamos, each capable of supplying a current for 25,000 lights. In the second engine-house will be placed the large engines and dynamos, of which there will be two sets, each dynamo 40 feet high and 500 tons in weight, to be worked eventually by a pair of vertical Corliss engines of 10,000 horse-power, although to begin with only half that engine power will be applied to each dynamo. The electric current will be alternately generated at high tension, conveyed by cables to the distributing station, and there converted by means of transformers to a lower tension, and finally converted to a low tension on the premises of the consumer, where the consumption will be registered by meter. The directors have arranged for the eventual supply of two million lights.

On the same day a visit was made to the Foreign Cattle Market, Deptford, the party being conducted over the premises by the superintendent, Mr. George Philcox.

The market was provided by the Corporation of the City of London, under the Contagious Diseases (Animals) Act of 1869, for the slaughter and sale of animals from scheduled countries, i. e. from countries where disease was known or suspected to exist. It cost in the first instance 255,000*l.*, and was opened for public use on January 1st, 1872. It was constructed on the site of H.M. Deptford Dockyard, and occupied a space of about 25 acres, which has since been increased to 30 acres, with river frontage of upwards of 1000 feet. The old shipbuilding slips and docks were filled up, and lairage for cattle and sheep provided on their site. The warehouses and other buildings were converted into slaughterhouses and other premises necessary for the purpose of carrying on the business of a large slaughtering establishment, as no animal is allowed to leave the market alive. For the purpose of landing animals consigned to the market, three substantial jetties were constructed, extending into the river 165 feet. Vessels ranging from 400 to 4000 gross tonnage land cattle at these jetties; Continental steamers can berth alongside at all states of the tide, and Atlantic steamers at about half-flood tide. Animals are landed immediately the vessel arrives, both by day and night. Covered lairage is provided for about 5000 head of cattle and 23,000 sheep, and there are about 62 separate slaughterhouses. A refrigerating machine has lately been added to the market, having chill rooms attached for the purpose of cooling fresh meat in hot weather. About $10\frac{1}{2}$ million animals have been landed and slaughtered at Deptford since the opening of the market.

October 7th, 1889.

HENRY ADAMS, VICE-PRESIDENT, IN THE CHAIR.

PIN-CONNECTED *v.* RIVETTED BRIDGES.

By JAMES HENRY CUNNINGHAM, ASSOC. M. INST. C.E.

TOWARDS the end of the year 1884, the writer made two designs for the superstructure of a bridge to carry a railway across the Mary River, in Queensland. There were to be three spans, the centre one being 120 feet long, and those at the sides each 80 feet in length. The clear width between the main trusses was to be 22 feet, and the structure was intended to carry a double line of railway, 3 feet 6 inch gauge, the live load being taken at two tons per lineal foot of bridge. Only one line of rails was to be laid at first, and the space intended for the other was to be occupied by a plank floor for waggon traffic. In the one design pin-connected skeleton trusses, such as are now commonly used in America, were adopted, and in the other, which was ultimately carried out, the trusses were of the lattice type with rivetted joints throughout. In this paper an attempt will be made to compare these designs and to show clearly wherein the one differs from the other, in the hope that such a comparison will serve to bring out distinctly, not merely the relative advantages of the two designs, but also the relative advantages of what may be called the rivetted and pin-connected systems of construction. This nomenclature, however, must not be supposed to imply that the use of rivets instead of pins in certain parts of the work is the only or even the most important difference between these systems, for the terms adopted merely indicate one very obvious difference, and if this is not kept in mind they may be misleading.

From Plate No. 1 the principal differences in the designs may be seen. In the rivetted one the cross-girders are placed about 5 feet 4 inches apart, while in the pin-connected one they are placed about 16 feet apart and have longitudinal steel stringers to carry the rails; further, the main trusses in the rivetted structure are of the Warren type with double web systems, those for the 80-feet spans having parallel booms, and the top booms of those for the 120-feet span being portions of circles. In the

pin-connected design the main trusses for the 80-feet span are also of the Warren type, but they have only single web systems, and the main trusses for the 120-feet span are of the Pratt type.

The rivetted design was made in accordance with a general outline which was furnished to the author, and the pin-connected design was prepared as an alternative, in order to ascertain whether a structure of that kind would be cheaper than the rivetted one. It was not desired to ascertain merely whether pin-joints would be cheaper than rivetted ones. That depends chiefly on the style of truss in which they are used. Probably nothing would be gained by using pins in such trusses as those of the rivetted design. Nor was it desired to ascertain merely whether deep trusses with long panels and simple webs would be cheaper than lattice ones. No doubt rivetted trusses similar in form to those of the pin-connected design, would be lighter than those of the rivetted one. But the point to be decided was, whether it would be economical to use trusses in which skeleton forms and pin-joints were combined, instead of rivetted lattice ones. Pin-joints possess many good qualities and much simplify the work both of designing and manufacturing, but by themselves they do not procure all the advantages which are claimed for the style of construction which is here named from them. Its economy of material, for instance, chiefly depends on other features which the use of pins makes it easier for the designer to introduce. There can be no doubt that for a long span a truss of the skeleton type is economical, and can be constructed with a much smaller amount of material than one of the other kind, whether the joints are rivetted or connected by pins. It is easy to account for this. Its depth permits the use of light booms. Its web consists of few members, and there are not many joints between that system and the booms, and therefore a saving is effected in gusset plates. Its web members being few in number become individually large, and require little of the secondary bracing which has to be added to light struts and ties, in order to give them sufficient stiffness. But when the web members are large, it becomes difficult to arrange their connections satisfactorily in rivetted trusses, owing to the large number of rivets which must be used in each joint. This difficulty can, however, be entirely got rid of by using pins, as by means of them, large members can be easily and satisfactorily connected. Another advantage gained by the use of pins is, that flat eye-bars may be used instead of rivetted members to take tensile stresses, thereby increasing the economy and simplicity of the structure. Briefly, it may be said that pins are chiefly of service because they are details which much simplify

the construction of skeleton trusses, and thus enable the designer to take full advantage of the facilities which trusses of that kind offer for economising material. The skeleton truss must therefore be regarded as an essential part of what is termed in this paper the pin-connected style of construction, and therefore a truss which would fairly represent that style must have long panels or bays, considerable depth, and a simple web system, as well as pin-joints. These important features could not have been secured in the structures now under consideration if in designing the pin-connected bridge the writer had adhered to the arrangement of the rivetted one, and he therefore adopted the long panels and simple trusses which have been described. He ventures to think that the rivetted design is fairly representative of its kind, and the whole object of making the pin-connected one would obviously have been frustrated if it had not been made fairly representative of its kind; for, otherwise, conclusions as to the merits of the two styles of construction which might be arrived at by comparing the two designs would be misleading and without value.

This amount of difference in the two bridges was unavoidable, or they would not have represented their respective styles of construction fairly.

But notwithstanding these necessary differences in their general arrangements, the two designs are fairly comparable, for they have much in common and are alike in the following respects:—In both, the maximum stresses were carefully calculated for the same loads, and the material was proportioned as accurately as possible, so that both should have the same strength without waste of metal. But although care was taken not to waste metal, economy was not carried too far, and secondary bracing in the form of tie-plates, reinforcing plates, and lacing was freely added in both designs, wherever it seemed to be required in order to secure durability or stiffness. For the same reason the sectional areas of many of the lighter members were made larger than was actually required by theory. These principles were specially adhered to in proportioning the parts of the pin-connected bridge, and their various dimensions were fixed with a view to secure excellence rather than economy. As an instance of this, an example may be given. In calculating the stringers, 25 per cent. was added to the live load, because every engine crossing the bridge brings nearly the full estimated load on to them. There did not appear to be the same reason for making such an allowance in the cross girders of either design, because they were calculated for a double line of railway, and but seldom would have to carry two engines at one time. It must, there-

fore, be understood that any points which there may be in favour of the pin-connected style of construction will not be overstated in what follows. No novelties were introduced into either design, and well-known and well-tried principles of construction were adhered to in both cases.

If two designs for a superstructure are found to be equally good in regard to strength and durability, the cheaper one must be considered better than the dearer, and in these circumstances cost is the standard by which their respective merits must be determined. But the cost of such structures depends mainly upon quantities which can be measured and stated numerically, so that in order to select the best bridge it is only necessary to ascertain and examine matters of fact. Unfortunately, it cannot always be assumed that two superstructures are equally good in respect of strength and durability, and therefore differences must be taken into consideration which are real and important, but yet cannot be stated in figures. The two designs under consideration were intended to be equally good, and some trouble was taken to make them so, as has been explained. For reasons, however, which have also been stated, they were very differently arranged, and therefore it may be thought that the one possesses qualities which more than compensate for any difference in cost. Stiffness and durability, for instance, are qualities which it is worth while paying something for, but they are also qualities about which there may be very legitimate differences of opinion, and one engineer may fairly consider a structure to be deficient in these respects, which appears to another to be sufficient. Accordingly, while giving the facts as to quantities of material and work on which the cost of these structures largely depends, the author will at the same time point out any features which may, in the opinion of some, make one design better than the other, and thus modify the conclusions which would be reached from the consideration of the figures alone. It must at the same time be borne in mind that the quantities dealt with are small, because even the 120-feet span is, comparatively speaking, a small bridge. It is small because the span is a short one for pin-connected trusses. No one claims that in general anything is gained by using such trusses in railroad bridges of less than 80 feet span, and as bridges are now frequently made 400 feet* long, a span of 120 feet may be considered small. It is also small because it was designed for a 3 feet 6 inches gauge railway, and the live load was estimated at only 1 ton per

* Mr. Theodore Cooper states that there are on the United States railroads 6½ miles of bridges having spans of 400 feet and upwards. Trans. Am. Soc. C.E., July 1889, vol. xxi. p. 46.

lineal foot of track, or nearly 50 per cent. less than would be required for an ordinary railway. However, as experiments with a small model sometimes serve to make clear the action of a large machine, so possibly an examination of the quantities of these small spans may indicate what will be found in larger ones of their respective kinds.

The quantities of material and work on which the cost depends may be conveniently divided into three classes, as follows, viz.:—

I. The quantity of material to be manufactured.

II. The quantity of material to be transported.

III. The quantity of work to be done in the field.

I. *The quantities of material to be manufactured.*—These are given in Table I. from which it will be seen that though there are great differences in the distribution of the metal, the trusses of the one design being much lighter than those of the other, still the total quantity of material is practically the same in both, there being only a difference of about 42 cwt. or $1\frac{3}{4}$ per cent. in favour of the pin-connected one. But in order to derive sound conclusions from these figures, the following points must be taken into consideration:—

(*a*) The lateral bracing is rather heavier in the pin-connected than in the rivetted bridge. But in the shorter spans the whole of the excess is due to the presence of struts at the ends of the trusses on the abutments, which are omitted in the rivetted bridge. In the longer span about half the excess is due to the form of the trusses, which requires more top lateral bracing than that of the rivetted ones, but fully half is due to the presence of end struts as in the shorter spans. These struts make the structure more complete, but they are not absolutely necessary, and it may be thought that the bracing in the rivetted bridge is sufficient without them. But on the other hand, although the laterals in the pin-connected design are heavier than in the other, the excess of metal is employed to make a more perfect system of bracing.

(*b*) In the pin-connected trusses for the 80-feet spans, there are vertical stiffeners, whereas there are no similar stiffeners in the rivetted trusses, and it may be doubted whether the latter will be as firm as the former. These vertical members are not essential parts of the trusses, but are put in because it is convenient to rivet the floor beams to them, and in order to stiffen the top boom laterally. Though they may be regarded as a kind of lateral bracing, their weight is included in the quantity given for the trusses, and the quantity given for laterals only includes cross struts, rods, and bolts. The trusses of the pin-connected spans are 16 per cent. (3 tons

per span) lighter than those of the rivetted spans, and it may well be thought that the metal in the lighter trusses is so arranged as to secure more lateral stiffness in their top booms than will be obtained in those of the heavier ones.

II. *Quantity of material to be transported.*—Weight alone is not a true measure of this quantity in work which is to go abroad, for space is very valuable on board ship, and ship-owners always take into consideration the bulk of packages as well as their weight. Forty cubic feet are allowed to the ton, and the owner of the ship has the option of measuring quantities of bridge work, either by weight tons or by space tons, selecting whichever happens to be most favourable to him in each particular case. Extra charges are also made for pieces which are too large or too heavy to be put on board by ordinary tackle. Hence it is important that girder work which is intended for the Colonies should be designed so that it may be shipped in pieces or packages which can be conveniently handled, and which will not incur extra freight charges, either on account of excessive bulk or weight. In dealing with pin-connected bridges the space tonnage will be found to be practically the same as the weight tonnage. The various web and lower boom members are pieces complete in themselves, and the top booms can be divided into sections of convenient weight and length. Top boom sections, floor beams, stringers, struts, and similar pieces, can be shipped by themselves, their ends and projecting parts being protected by wooden blocks; flat bars and rods can be tied together in bundles; and the smaller parts, such as pins, bolts, nuts, and rivets, can be packed in wooden boxes. With a little care, much the same result may be obtained in the case of the 120-feet rivetted span. The trusses for that span must obviously be taken apart into pieces similar to those of a pin-connected bridge, just described; but the case of the rivetted trusses for the two 80-feet spans is different. These need not necessarily be taken wholly apart, but might each be divided into four large sections, and therefore the question arises whether it is cheaper to take them to pieces and thus increase the cost of erection, or to ship them in large sections and leave as little rivetting as possible to be done in the field? Generally it will be found cheaper to take such girders wholly apart, separating the web from the booms, as the cost of the extra work required to put them together again is not nearly as great as the extra freight charges which would be incurred by shipping large pieces of girder. But in order to ascertain the exact state of the case in regard to these 80-feet spans, the ship's measurement was carefully worked out, and it was found that if the main trusses were taken wholly apart it would be practically the same

as the weight, whereas, if they were divided into four large sections the ship's measurement would exceed the weight by 70 per cent., or about 21 tons per span. The freight being 2*l.* 10*s.* per ton, something like 105*l.* would be added to the cost of transportation, to say nothing of increased rates. As 100*l.* will pay for a great deal of work in erecting, it was evident that it would be much cheaper to take those girders wholly apart, rather than to ship them in large sections. It will, therefore, be assumed in considering the next part of the subject, viz. the quantity of work to be done in the field, that these girders are taken wholly apart for shipment, as in fact was the case.

III. *Quantity of work to be done in the field.*—Before considering the work of erection, it may not be out of place to refer to a part of the work, usually done in the shops, which is closely connected with the field work, viz. the temporary erection. In rivetted work it is necessary to fit up all the joints temporarily, so as to ensure accuracy. In pin-connected work this need not be done. This saves a good deal of shop work in the case of the pin-connected bridges, as only the top boom sections have to be fitted up in the shops. But even if the whole bridge has to be put up, to be tested with an actual load, there will still be an advantage in favour of the pin-connected structure, owing to the small number of its joints and to the facility with which they can be connected and taken apart.

As it has been shown that the rivetted spans must be taken apart and shipped in pieces similar to those of the pin-connected spans, it is fair to assume that much the same kind of staging and tackle would be needed in both cases. More top staging might be required for the pin-connected 120-feet span than for the rivetted one, but in the latter a greater number of joints would have to be fitted together, so that the cost of staging, handling, and putting together may be taken to be the same in both cases. The total cost of erection cannot well be estimated in either case by measuring quantities of any kind, for there is only one part of the work which can be satisfactorily measured, that is the rivetting. Rivetting is at least an important factor in erecting bridge work, and as it can be measured accurately and easily, it may serve as a criterion by which to estimate the amount of field work involved in the erection of the two designs. Table II. shows the amount of rivetting required both in the shop and in the field, and it will be seen that, roughly speaking, there are 2000 rivets to drive in the field in each rivetted span in excess of the number required to be driven in each pin-connected span. Dealing only with totals, it will be found that in the pin-connected structure 96 per cent. of the rivets are to be driven in the shop and 4 per

cent. in the field, whereas in the rivetted spans 82 per cent. are to be driven in the shops and 18 per cent. in the field. The excess of rivets to be driven in the field in the rivetted spans amounts numerically to 5952. Taking the cost of driving $\frac{3}{4}$-inch rivets in the field at 8*s.* 6*d.* per 100 (200 per day), it will be seen that 5952 rivets are equivalent to about 25*l.* in money and to 30 days in time.

One other remark may be made here on the results shown in Table II., though it does not directly bear on the work of erection. In both designs shop-rivetting could be done by machines, and ought to be so done. Machine-rivetting is cheaper and more expeditious and more likely to be well done than hand work, especially hand work done under the difficulties which must inevitably be encountered in the field. A structure which requires 4 per cent of the rivets to be hand driven is therefore, in respect of this kind of workmanship, preferable to one in which 18 per cent. of the rivets have to be driven by hand.

The results which have been arrived at by comparing the two designs may now be briefly summed up, so that an opinion may be formed as to the relative merits of these structures.

(1) The two designs are fairly comparable, the same loads, factors of safety, and general dimensions being used in both.

(2) The total quantity of material is practically the same in both.

(3) The pin-connected spans have more complete systems of lateral bracing than the rivetted ones.

(4) The pin-connected trusses for the 80-feet spans have better vertical stiffening than the rivetted ones.

(5) Both structures can be packed and shipped in conveniently sized pieces.

(6) Both structures can be erected by means of the same kind of staging and tackle.

(7) The pin-connected spans do not require to be wholly erected in the shops to ensure proper fitting. If erected for testing, they can be more easily fitted up and taken apart than the others.

(8) In the rivetted spans, 18 per cent. of the rivets must be driven in the field, whereas in the pin-connected spans only 4 per cent. of the rivetting has to be done in the field.

These considerations lead to the conclusion that the pin-connected design is, on the whole, better than the other, but it must be admitted that in this case the practical advantages do not appear to be great. This is partly because these particular spans are comparatively short and light. The pin-connected design could not have been adopted without obtaining authority from the Colony, and this would have involved delaying the

work for three months at least. It appeared to the author that any advantages which it possessed would not compensate for such a delay, and, as has been stated, the rivetted design was built.

The relative merits of the two designs are, however, of less general interest than the relative merits of the two systems of construction of which they are types. The former subject has been gone into at some length, principally, as it was thought that by doing so some light would be thrown on the latter. The general question will now be considered more fully, and the author will briefly state what he believes to be the main points of the case for pin-connected bridges as compared with rivetted ones, and then examine these points in the light of the facts which have been noted in the first part of this paper.

Three claims may be made on behalf of pin-connected bridges :—

I. That they are as durable and strong as rivetted ones.

II. That they are more economical, a smaller quantity of material sufficing for a pin-connected bridge than for a rivetted one of the same strength.

III. That they can be more easily and quickly constructed in the shops and erected in the field.

I. *Are pin-connected bridges as durable and strong as rivetted ones?*—Clearly this is a question about which little can be learned from any mere designs. Those who have examined the drawings may be disposed to admit that there is no very apparent reason for supposing that the pin-connected bridge will not last as long as the other. But this is an all-important question, for if pin-connected bridges are not as good as rivetted ones, no more need be said. Even a great amount of economy in material and facility in construction would be too dearly purchased by any sacrifice of thorough stability and durability. The matter can only be satisfactorily settled by experience, and it may therefore be worth while to state here some facts derived from that source. Within recent years an enormous number of pin-connected bridges have been constructed in America, some of them having very large spans, and there is nothing to show that these bridges have proved unsatisfactory in any way, or are likely to become so. It is true that various details which were at one time common in America have been discarded, and rivets are now often used in place of less firm connections, but the pin-joint holds its own. There is no tendency to substitute rivets for pins in the main joints of the trusses. A few of the more important pin-connected bridges which have been built recently are briefly described in Table III. The fact that the engineers named in the table, men who have had ample opportunities of testing pin joints and skeleton forms in every way,

have adopted such joints and forms in the very important works referred to, goes far to show that there is no ground whatever for doubting either the stability or the durability of a properly constructed pin-connected bridge.

II. *Are pin-connected bridges more economical than rivetted ones?*—This is a question on which the quantities given in the earlier part of this paper may be expected to throw some light; but, as already remarked, it must be remembered that the quantities dealt with are small, because they belong to bridges which are short and light.

On glancing at Table I., we find that the pin-connected trusses are considerably lighter than the rivetted ones, both for the 80-feet and for the 120-feet spans, but that this saving is only effected at the expense of a serious addition to their floor system. The weights of the floor systems per lineal foot are not affected practically by the lengths of the spans, but only by the form of the trusses, and the floor of the pin-connected bridge is much heavier than the floor of the rivetted one. Some may think that it is also much better, and that the steel stringers are more satisfactory than the wooden ones, but this need not be discussed now. The laterals will not here be taken into consideration, because they cannot be fairly compared, for reasons which have been stated above. Even if they are supposed to add something to the weight of the pin-connected structure, the amount would not be sufficient to modify the figures materially. The handrail and shoes will also be omitted, as they are entirely local features, and have no bearing on bridge superstructures in general, though they may fairly be considered when the merits of the two particular designs are being examined. The quantities in the trusses and floors are therefore the only ones which need be taken into consideration now, and on examining the figures given in Table I. it will be seen:—

(1) That the pin-connected trusses for the 80-feet spans are 16 per cent. lighter than the rivetted ones.

(2) That the pin-connected trusses for the 120-feet span are 22 per cent. lighter than the rivetted ones.

(3) That in the 80-feet pin-connected spans the amount of metal added to the floor nearly equals the amount saved in the trusses, and the total quantity of metal in each complete span is practically the same as the quantity in the corresponding rivetted span.

(4) That in the larger pin-connected span more is saved in the trusses than is added to the floor, so that the complete span is 6 per cent. lighter than the rivetted one.

So far as these figures can throw light on the subjects, they indicate:—

(*a*) That pin-connected trusses are considerably lighter than rivetted ones, and that the percentage of saving is greater in long than in short spans.

(*b*) That the floor of a pin-connected bridge is heavier than the floor of a rivetted one, but that the saving in the trusses exceeds the additional metal required in the floor.

This has been found to be the case in America. There, bridge designs have been subjected to severe competition, and the economy of every kind of structure has been thoroughly tested by the rivalry of builders who are continually struggling to supply the best article at the lowest price. The result may be noticed in a tendency to increase the bay or panel length, retaining at the same time a considerable depth of truss. In short spans the designer can at best save little, because there is little room for the exercise of discretion, and the whole quantity involved is small. But as the span increases, the proportion of metal in the trusses tends to increase more rapidly than that in the floor. In long spans the trusses are, therefore, that part of the structure in which it is most important to economise. They are also that part in which it is most possible to economise, for they may be made to assume any form which seems good to the designer, whereas he has little or no choice as to the way in which the floor may be made. The longer the bays and the greater the depth of the main trusses, the lighter they will be. Practical considerations in each case will indicate the limit beyond which it is not judicious to extend the panel length, but within this limit long bays and the great depth of truss which they involve give economical results, even although a shorter panel might give a lighter floor. As has already been stated, the economy of material in pin-connected trusses depends primarily on their skeleton form, the advantage of the pin-joint being merely the facility it affords for connecting together the members of skeleton trusses, which are necessarily large. The pin-joint also secures economy in labour, but that will be considered under the third head of this inquiry, viz.:—

III. *Can pin-connected bridges be more easily and more quickly* (1) *constructed in the shops, and* (2) *erected in the field, than rivetted ones?*

(1) As to the first part of this question, the two designs under consideration give no very definite answer. Mere opinion as to the relative ease with which the work shown on the drawings can be executed is of little value, because the views of practical men often differ widely as to the facility with which shop work can be done. Even experience is often misleading, owing to exceptional features in the structures from which it has been obtained. A glance at the drawings, especially

those for the 120-feet span, will, however, show one thing, viz. that the arrangement of the pin-connected bridge is more likely to secure accurate and rapid work in the shops, than that of the rivetted one. All the parts of the pin-connected bridge are straight pieces, and can be made directly from drawings which the engineer can himself check, whereas the rivetted spans must be laid out from full-sized templates, which must be made by a pattern-maker. Men generally produce better work when required to work from definite dimensions and from drawings which leave nothing to their own discretion. The work goes on better, many parts can be put in hand at once, and the delays caused by uncertainty as to how this and that is to be done are avoided. Fully dimensioned drawings can easily be made for every part of a pin-connected bridge, but cannot so easily be made for every part of a rivetted one. Even if such drawings were prepared, templates made by the pattern-maker would have to be substituted for them in the shop, particularly in curved parts of the work or in bevel joints, such as the connections between the diagonal braces and the booms. In this, as in many other things, only experience can give understanding, and it is difficult to convince those who have not made pin-connected trusses of the advantages which those who have made such work find in it. As regards this, American experience may have some weight. The facility with which accurate and minutely detailed drawings can be made, and the rapidity with which construction can be carried out, is undoubtedly one reason which disposes the American engineer to use pin-connected work. Special tools are not needed, though of course they may be used with advantage by those who possess them; but ordinary pin-connected work can be properly made in any shop which is fitted with the usual punching, drilling, and planing machines, also with lathes and a steam hammer.

(2) As to the second part of the question, which concerns the work of erection in the field, an examination of the two designs will reveal one decided advantage in favour of the pin-connected bridge. Some may claim that the work of fitting the various members together can be more easily and quickly accomplished in the pin-connected than in the rivetted spans. Probably it is so, but this is not evident from the drawings. It is, however, quite evident that much less rivetting has to be done in the field on the pin-connected than on the rivetted bridge. Table II. shows that while in the pin-connected bridge 1308 rivets must be driven in the field, in the rivetted one 7260 have to be driven. The difference is still more marked taking the trusses alone. In those of the pin-connected structure 416 rivets must be driven in the field, whereas in those of the rivetted structure 6356

have to be driven. Granting that the handling and fitting would be much the same in both structures, it must be remembered that when a pin-joint is fitted together it is finished, but when a rivetted one is fitted a great deal of work remains to be done. How great the quantity of this work is in a rivetted, as compared with a pin-connected bridge, the figures show. Field rivetting is the slowest and most difficult kind of rivetting, and therefore the most likely to be indifferently executed, and the smaller the number of field-driven rivets in a bridge, the better the work is likely to be and the quicker it will be completed. One or two examples may here be given to show the speed with which some large pin-connected bridges have been erected in America. The cantilever bridge at Niagara, consisting of 2000 tons of iron and steel, was erected complete in twelve weeks and one day, and in two weeks more the track was laid and an engine was run across. The Pauli trusses, 360 feet in length, in the two channel spans of the Monongahela Bridge, at Pittsburg, were completed in nine weeks. Three 400-feet spans at Bismarck, weighing over 1300 tons, were put up in seventy-two days.*

In conclusion, the results which have been arrived at may be briefly summed up. The quantities in the two designs may impress upon the mind the great economy of material which can be obtained in trusses by using long panels and a considerable depth, an economy which is by no means wholly neutralised by the metal which must be added to the floor system on account of the great panel length. Pin joints are details which much simplify the construction of large skeleton trusses, and when they are used the work of field rivetting is greatly reduced. The designs give some idea of the amount of this reduction. These facts, combined with the results of American experience, seem worthy of the consideration of English bridge-builders. The pin-connected system has been much misunderstood. Badly designed structures have been brought forward as specimens of its results. Attention has been too much directed to the pin joint, which is in itself a mere detail, and is chiefly of value in connection with skeleton forms of truss, especially in long spans. Too great advantages may have been claimed for this style of construction, and in some cases its exponents may have used too light sections in their zeal to economise. But in spite of all this, the system holds its ground. An immense amount of skill and ingenuity has been expended in perfecting the designs and securing excellence both in material and workmanship, the result of which may be seen on the American railroads to-day. English engineers and

* Note A, page 148.

manufacturers are quite aware that they have no monopoly of the markets of the world, and that they must be on the watch to adopt improved methods of construction if they are to continue to supply railway material to the Colonies and India. They know that they must produce a good article cheaper than others can, if they are to hold their own in these markets. But how is this to be done in bridge-building? In what directions are improvements to be sought which will reduce the cost of bridge superstructures without impairing their strength and may even increase it? The author trusts he may be permitted to offer one or two suggestions in reply to such queries. It is not likely that any new form of truss will of itself afford highly economical results. Economy is more likely to be found, if sought for, in the careful designing of trusses of the usual forms than in the invention of new types. But the work of designing is specially the work of the engineer. He can do much to secure economy of material by calculating stresses accurately, and selecting and distributing metal judiciously. He can do much to secure economy of time and labour by preparing full and accurate drawings, by selecting details which can be easily made, and by arranging the work so that machine tools may be used in its construction, and time saved in its erection. The writer believes that those who attempt to effect economies in bridge superstructures by these methods will find their work much simplified by a judicious use of the pin joint.

NOTE A.

As to Time Occupied in Erection.

Mr. Theodore Cooper gives some interesting information as to the rapidity with which pin-connected trusses can be assembled and swung clear of the false works or temporary staging, in the 'Trans. Am. Soc. C.E.,' July 1889, vol. xxi. p. 39.

He states that any span up to 250 feet can be erected so as to be self-sustaining and independent of the false works in sixteen working hours, without unusual exertion. He also gives the following facts as to the erection of large spans. In October 1888, two spans of 518 feet 6 inches were erected at Cairo, on the Mississippi. The first was put up in six days and the second in four. The trusses were 61 feet deep, and were divided into seventeen panels of 30 feet 6 inches, and each span weighed 917 English tons. The whole time occupied during the erection of the two spans and moving the false works was one month and three days, five days being lost waiting for the completion of the masonry.

A correspondent has kindly sent me the following particulars of the erection of the three spans of 400 feet near Kansas City, on the Missouri, referred to in Mr. Whittemore's letter (see page 166). This work was completed in September 1887. The following average time was occupied in the erection of one span :—

Driving piles for false works, and capping same	11 days.
Raising bents 50 feet high	5 „
Putting flooring on same, and erecting traveller	5 „
Raising and connecting ironwork (The last span was done in 3 days 8 hours.)	5 days 3 hours.
Packing lower chord bars, and putting in floor beams and track system	8 days.

While one span was being raised the false works for the next were put up, and in this way erection went on uninterruptedly.

TABLE No. I.

QUANTITIES OF STEEL. (In cwts. of 112 lbs.)

Parts of Structures.	Steel in		Excess of Steel in	
	Pin-connected Bridge.	Rivetted Bridge.	Pin-connected Bridge.	Rivetted Bridge.
80-feet span :—	Cwts.	Cwts.	Cwts.	Cwts.
Trusses	310·13	369·14	..	59·01
Floor	276·22	219·47	56·75	..
Trusses and floor	586·35	588·61	..	2·26
Laterals	23·53	14·37	9·16	..
Total	609·88	602·98	6·90	..
120-feet span :—				
Trusses	507·38	650·89	..	143·51
Floor	411·12	326·56	84·56	..
Trusses and floor	918·50	977·45	..	58·95
Laterals	89·87	70·24	19·63	..
Total	1008·37	1047·69	..	39·32
Handrail, shoes, pier girders, &c. ..	231·60	248·00	..	16·40
Two spans of 80 feet	1219·76	1205·96	13·80	..
Total in whole structure	2459·73	2501·65	..	41·92

TABLE No. II.

Quantities of Riveting.

Parts of Structures.	Number of Rivets to be driven.						Excess of Rivets to be driven in Field.	
	In Pin-connected Bridge.			In Rivetted Bridge.				
	In Shop.	In Field.	Total.	In Shop.	In Field.	Total.	In Pin-connected Bridge.	In Rivetted Bridge.
80-feet span :—								
Trusses	5,562	160	5,722	5,180	2,122	7,302	..	1,962
Laterals	138	..	138	12	85	97	..	85
Floor	3,356	224	3,580	3,032	112	3,144	112	..
Total	9,056	384	9,440	8,224	2,319	10,543	..	1,935
120-feet span :—								
Trusses	8,780	96	8,876	10,608	2,112	12,720	..	2,016
Laterals	558	108	666	650	342	992	..	234
Floor	4,926	336	5,262	4,624	168	4,792	168	..
Total	14,264	540	14,804	15,882	2,622	18,504	..	2,082
Total in two spans of 80 feet	18,112	768	18,880	16,448	4,638	21,086	..	3,870
Total in whole structure ..	32,376	1,308	33,684	32,330	7,260	39,590	..	5,952

TABLE No. III.—Pin-Connected Bridges.

Note.—These Bridges have been selected because they are described in publications which are easily accessible. Many of the Spans in the approaches are not mentioned.

Name.	Number and Length in Feet of Spans.	Date of Construction.	River.	Railway.	Engineer.	Contractor.	Reference.
Port Perry ..	1 of 260 8 of 140	1878	Monongahela	Pennsylvania; Pittsburg, Virginia, and Charleston Brch.	Joseph M. Wilson, M. Inst. C.E., M. Am. Soc. C.E.	Keystone Bridge Co.	Proc. Inst. C.E., vol. lx. p. 309.
Minnehaha ..	1 of 324 2 of 272	1880	Mississipi ..	Chicago, Milwaukee, and St. Paul.	D. J. Whittemore, M. Inst. C.E., and C. Shaler Smith, M. Am. Soc. C.E.	Edgemoor Iron Co.	American Engineer, May 1881.
Plattsmouth ..	3 of 200 2 of 400	1879–80	Missouri ..	Chicago, Burlington, and Quincy.	George S. Morrison, M. Am. Soc. C.E.	Kloman; Keystone Bridge Co.; Kellogg & Maurice.	Railroad Gazette, Dec. 10th & 17th, 1880.
Bismark	3 of 400	1881-2	Missouri ..	Northern Pacific ..	George S. Morrison, M. Am. Soc. C.E.	Detroit Bridge Co.	Engineering, vol. xxxvii. p. 34.
Monongahela ..	2 of 360	1882–3	Monongahela	Smithfield Street, Pittsburg.	G. Lindenthal, M. Am. Soc. C.E.	Kloman; Kellogg & Maurice.	Trans. Am. Soc. C.E., vol. xii. p. 353.
Point Pleasant	1 of 416 3 of 250 1 of 200	1883	Ohio	Ohio Central	Keystone Bridge Co.	Keystone Bridge Co.	American Engineer, vol. vi. p. 209.

TABLE No. III. (*continued.*)—PIN-CONNECTED BRIDGES.

Name.	Number and Length in Feet of Spans.	Date of Construction.	River.	Railway.	Engineer.	Contractor.	Reference.
Fraser River ..	2 of 105 1 of 315	1884	Fraser	Canadian Pacific ..	C. C. Schneider, M. Am. Soc. C.E.	Hawks Crawshay & Co., Gateshead, England.	Engineering, vol. xxxviii. p. 219.
Niagara Cantilever.	2 of 195 1 of 470	1883	Niagara ..	New York Central ..	C. C. Schneider, M. Am. Soc. C.E.	Central Bridge Co.	Trans. Am. Soc. C.E., vol. xiv. p. 499.
Kentucky and Indiana.	2 of 480 1 of 360 2 of 260 1 of 240 draw 370	1883–5	Ohio	Railway and Highway.	Edward Hemberle, M.Am. Soc. C.E., and Chas. Mac Donald, M. Am. Soc. C.E.	Kellogg & Maurice; Union Bridge Co.	Trans. Am. Soc. C.E., vol. xvii. p. 111.
Poughkeepsie	2 of 500 3 of 520	1886–8	Hudson ..	Railway	Union Bridge Co.	Union Bridge Co.	Trans. Am. Soc. C.E., vol. xviii. p. 199.
Blair crossing ..	3 of 330	1882–3	Missouri ..	Missouri Valley and Blair Railway Company.	George S. Morrison, M. Am. Soc. C.E.	Keystone Bridge Co.	Engineering, vol. xliv. pp. 250, 304, 367.
Sibley	3 of 400 1 of 250 1 of 200 2 of 175	1887	Missouri ..	Atchison, Topeka, and Santa Fé.	O. Chanute, M. Am. Soc. C.E.	Edgemoor Iron Co.	Trans. Am. Soc. C.E., vol. xxi. p. 97.

DISCUSSION.

The CHAIRMAN considered that engineers were more disposed to adopt the Pin-connected Bridge than they were formerly, but there was an insular prejudice in favour of rivetted connections which had to be overcome. The paper was a very valuable one because of the comparisons which it enabled engineers to make between the one system and the other. He moved a vote of thanks to the reader of the paper, which latter he hoped would be accompanied with the diagrams when published in their Transactions.

Mr. A. T. WALMISLEY thought the paper a most useful one, because, like the paper which was read at the close of last session, dealing with foundry work, it was a practical contribution to a most important question of the day. Judging by the details given by the author, there did not seem to be any particular saving of total weight, when the platform was also taken into consideration, between the adoption of the pin or the rivetted bridge system; therefore the chief merit in the former method appeared to be the facility with which the erection of bridges could be proceeded with when pin-connections were employed. No doubt abroad, where skilled labour was difficult to obtain, it was necessary to bear this fact in mind. Rivets were most useful in connections where there were several plates to be connected together, because they tended to keep the bars and plates constituting any member of a structure in such close and continuous contact as to effectually exclude all moisture and so avoid rust; whereas, in pin-built bridges, rust was apt to get in between the openings of plates placed side by side, when such openings expanded under the influence of compressive strain, and into such apertures the painter's brush could not work. That certainly was an argument in favour of rivetted structures. More attention had been paid of late to the value of pin bridges than formerly. Pins were frequently made of larger diameter than was necessary to provide a cross sectional area sufficient to resist the shearing strain produced by the usual loads, particularly when they came in double shear, the reason being to prevent their bearing surface being called upon to take more than $3\frac{1}{2}$ or 4 tons to the square inch. It was the same with rivets. He had no doubt that the study of the result of bearing areas with regard to pins had led to greater attention being given to bearing-areas in rivetted connections. When struts had to be connected to a pin, it was a great advantage to use a pin of large diameter, because the larger the pin's diameter the greater would be the frictional resistance developed between the pin and the soffit-bearing, whereas the smaller the pin the less frictional resistance would be provided. Hence

the larger the diameter of the pin the stronger would be the strut, because it would more nearly approach the case of a fixed end column, in which the lateral deflection is less than in the case of a spherical end or free or imperfectly fixed column. The author's diagrams exhibited nuts at each end of the pin. This was certainly preferable to a cotter fastening. A spanner applied to a nut, acted with sufficient leverage to squeeze the bars close together, whereas with a cotter fastened in the end of a pin, the bars could never be quite close together, and then one or other of the bars was apt to produce a bending moment in the pin, which was very detrimental to a structure.

Mr. F. WENTWORTH-SHEILDS said that he had always considered that rivetted joints gave better results than pin joints, especially as the amount of deflection for the former under similar circumstances was less; and he believed that the greater or less deflection of the structure under equal conditions afforded a very fair test of its durability. He had found that unless a pin had a very hard surface it was liable to be indented under pressure, and that therefore pins in almost all cases had to be increased in diameter above the sectional value of their area, but that rivets were not so liable to this drawback; and moreover the strength of rivetting was materially assisted by the plates being drawn closely together in the rivetting process, thus causing an additional resistance to the separation of the plates almost equal to the resistance caused by the rivets themselves. It was to be regretted that the author had given no tests of deflection, so as to allow of a comparison in this respect between pin and rivet-fastened girders being instituted. Nevertheless, his paper was very valuable; his results were stated in a manner clear and easy to refer to, and he gave an excellent description of the most recent performance in girder bridge building of our ingenious American brethren.

Mr. SHERLEY PRICE asked what would be the effect if some of the holes in a series of plates were not precisely opposite one another. If a rivet was put in hot, it would fill up the space and make a solid mass, whereas a pin would not. If it did not, what was the effect upon the pin?

Mr. GEORGE A. GOODWIN remarked that he did not agree with the statement "that secondary bracing was not so much required in struts of pin-connection bridges, because being fewer of them they were necessarily stiffer than those in lattice girders," for although they had a larger area of cross section, their increased length necessitated stiffer bracing.

With regard to being able to use a series of flat tie-bars in a pin-connection bridge, that advantage accrued equally well in an ordinary lattice type; and further, the close proximity of the bars to each other was a disadvantage, owing to the

impossibility of keeping them properly painted in between—and he had remarked that some of the ties in the Charing Cross Railway Bridge, had bulged considerably, owing to the formation of rust.

He did not believe it was possible to generalise a comparison between pin and rivet connection bridges; they both had their respective claims and uses, and it all depended on the design most suitable to surrounding circumstances as to which type should be adopted. No doubt that for erection in far-off countries, where labour was dear, pins were preferable, being cheaper to erect. He had had considerable experience in bridge work, and considered that in this country the construction of a pin bridge would cost as much as a rivetted one.

In the United States, special plant was available for making the tie-bars, while none existed here. The best system he had seen in this country, although an expensive one, was to obtain bars as wide as the extreme diameter of the eyes, and which were formed at the ends of the bars by stamping; leaving the centre part or body of the bar to be parted off.

With reference to accuracy, he considered the rivet type could be just as easily and accurately constructed as the pin one; it was only necessary to make iron templates of all the members, drill them out about $\frac{1}{2}$-inch larger diameter than the size of the rivet, then bush them with steel ferrules and drill through them into the actual work, thus avoiding all possible chances of inaccuracy. A slight difference in the pin holes would not constitute a practical drawback, and would probably only affect the strain by a very small percentage.

The fact of there being a large number of pin bridges in America was a negative proof that that type was best. He preferred to adhere, other things being equal, to the rivet connection and closer lattice; they were stiffer and stronger, and rivets distributed the strains over a larger area and in a more satisfactory manner than pins, which only act, at the best, on a section limited by the diameter of the pins.

The speaker then referred to certain experiments which had been made to determine the question that rivets acted largely by reason of the lateral pressure put on the plates they passed through, and friction set up, rather than acting only, as is generally considered, in shear.

Skeleton trusses had the advantage that, owing to their increased depth, overhead bracing was generally capable of being applied; but that type meant more dependence on isolated parts of the structure than in close lattice girders, and which in case of flood, accident, or failure, might mean the loss of the bridge.

Lastly, as regards construction, he was strongly of opinion that all bridges, pin or otherwise, should be put together

complete in the maker's works so as to ensure accuracy, and to avoid the possibility of a hitch occurring at the site when they came to be erected.

Mr. C. F. FINDLAY said that several years ago he had opportunities of studying the construction of American bridges, and he went over a good many of them, and certainly thought that the question brought before them by the author was a most valuable one to discuss, but not a subject on which they could form a hard and fast opinion. In most instances in America, a pin bridge had many advantages, but it did not necessarily follow that the same advantages could be realised in England. The saving in erection was no doubt very large, comparing the cost of one kind of bridge with the other, but an engineer in England had to consider the fact that contractors here would not build a pin bridge for anything like the same price as a rivetted one. A pin bridge was not as well adapted for carrying heavy or fast traffic as a rivetted bridge, because, however good the work might be, a pin bridge would always give rise to a good deal of vibration. A rivetted bridge did not vibrate to nearly the same extent as a pin bridge. There were some parts of America where the trains travelled at a much greater rate than in others, and the bridges differed in construction according to the character of the traffic over them. In the Colonies the circumstances were much more like those in America than those in England, and he thought that for them the advantages of pin bridges would very often preponderate. Greater familiality on the part of manufacturers with pin bridges, especially in the manufacture of eye-bars, would also enable them to reduce the prices they now charge, which are higher than there is any real occasion for, in comparison with those of rivetted work.

Mr. J. W. WILSON, Jun., thought that after hearing the author's paper, a further advantage might be derived from its perusal, especially as regards the points of comparison suggested by the tables. The pin-connected bridges appeared to be those generally preferred abroad for large spans, and that should be borne in mind in expressing an opinion as to which was the preferable plan to adopt. It should, however, be remembered that it was not always the custom to fit pins before the bridges were erected, and if it became necessary to bore the link ends for the pins when the bridge was *in situ*, that would add considerably to the cost of labour in the field. There was much which might be said in detail about the pins. Undoubtedly, as a previous speaker had remarked, pins were of necessity made larger than was warranted by the shearing stress alone which came upon them. To meet this point, a suggestion had been made that the pins should be hollow,

but this would add greatly to the cost, and the saving in metal would not be worth consideration. They could hardly expect to get all the link ends thoroughly tightened up, so as to keep out the damp entirely, nevertheless he did not see why they could not be arranged to allow of sufficient accessibility to these special parts of the structure.

With reference to deflection, it was evident that in a pin-connected bridge, the diagonals could rock, but as to what was the result with rivet-connected diagonals it was not easy to say. He thought that was an argument against rivet connections. With reference to the sketch made on the black board, he saw no difficulty in making rivet holes run true through any number of plates, if necessary, especially in the case of the diagonals of such work as was under consideration. There was no doubt about rivets being thoroughly good in themselves. The question of the supporting of the floor would have something to do with the opinion at which they would arrive in respect to the pin-connected or the rivet-connected bridges shown in the diagrams. In one case the cross girders came at the junction points of the diagonals and booms; in the other they were also to be found between those joints. In conclusion, he should like to ask the author which of the two types shown would be most likely to withstand satisfactorily the considerable horizontal stress which Mr. Benjamin Baker had shown would certainly come upon a railway bridge from the sudden application of continuous brakes.

Mr. PERRY F. NURSEY said the question of pin attachments as against rivetting, was an important one, and the comparative values of the two systems might be illustrated by an example of pin-connection which had been brought under his notice some years since, by Mr. T. George, the County Surveyor of Carmarthen. Mr. George had occasion to overhaul the Llandovery suspension bridge, when he found that 160 iron bolts from which the suspending rods carrying the platform depended, were very seriously corroded. The bolts were originally $1\frac{1}{4}$-inch in diameter, but had become reduced by oxidization in some places to $\frac{3}{4}$-inch in diameter [as shown by a drawing exhibited], thus seriously imperilling the safety of the structure. Upon the general question, he (Mr. Nursey) would observe that he gave preference to rivetted joints, not only as avoiding corrosion, and as affording a greater gripping surface, as had been mentioned, but because the joint was distributed over a larger area, giving greater uniformity of stress throughout the structure.

Mr. H. N. MAYNARD said, he had generally found iron pin-connected bridges heavier and more costly per ton than lattice bridges. For instance, an 80-feet span pin-bridge design was put into his hands, having swelled links, to carry a rolling load of

1½ ton per foot, with the floor on the lower flange, and this design was estimated to require 50 tons of iron. He made a lattice bridge to do the same work, with 35 tons of iron at 2*l.* per ton less. He was now making designs, in fact the ironwork was in hand for one of them, of a 90-feet span with railway on top, of a weight of 33 tons 16 cwt., and an 80-feet span, with railway on top, of 29-ton weight. It had been customary to make 60-feet span pin bridges (road on top), with about 24 tons, while a 60-feet lattice took 18 tons; and if the railroad was carried on the bottom flange, about seven tons more iron was used. Similarly, a 150-feet lattice girder required 99 tons, while a pin bridge was reckoned to require 140 tons of iron. A bridge composed of 150-feet spans, however, viz. the Crumlin Viaduct, with which he had been intimately acquainted from the beginning, was originally made with only about 45 tons of iron in a pair of girders for single line on the top. This unusally small quantity of iron might be accounted for by the fact of its being covered with planking 6 inches thick, and therefore no cross girders or rail girders were used. But this planking in a few years became decayed, and then its use in distributing the weight was lost and cross girders and rail girders were used. The reason why lattice bridges were more used than pin bridges, where timber was rather dear, was that for spans over 40 feet or 50 feet, the cross girders came so far apart in pin bridges, as to necessitate heavy rail bearers, which was obviated in a double system of lattice. But if they were covered with thick timber, so as to properly distribute the weight from the passing trains, less ironwork was required. The timber required frequent renewal, and was risky if not well looked after. In comparing the rivetted connection of a tie-bar with the pin connection of the same bar, take for example a flat bar 10 inches by 1 inch, rivetted with 11 rivets 1 inch diameter $= 11 \times \cdot 7854 = 8 \cdot 63$ inches, so arranged that only two rivets were in the same line of cross section of the bar, there would then be $10 - 2 = 8$ square inches of effective sectional area for tension in that bar, and something more in rivets. A pin, to be of equal area to the 11 rivets, must be say 3¼-inches diameter $= 8 \cdot 2$ square inches. That pin cut away from the 10-inch bar a width of 3¼ inches, leaving only 6¾ square inches, whereas the rivets would leave 8 inches, thus the rivets would be 18½ per cent. stronger than the pin joint, and a strip the width of the diameter of the pin, nearly as long as the bar, was wasted. A pinned bar needed to be at least 11¼ inches in width. Of course that had led to the question of swelled bars, and a bar 8 inches wide, swelled at the end to 11¼ inches would be necessary. That bar, it might be said, would be 8 inches instead of 10 inches, only swelled at the ends, and from 16 to 18 per cent. lighter, according to its length.

But the saving thus effected was more than counterbalanced by the increased cost per ton of the bars in that form, viz. about 30 to 50 per cent. above the price per ton of plain bars. With respect to friction of rivets, one important thing in favour of rivets was the friction of the plates sliding one upon another under the grip of the shrinkage of the rivets cooling after being rivetted whilst hot. The value of that friction was generally neglected in calculations of strength, but in reality it was very important, for it had been found that for a rivet which took 12 tons to shear, it has held together the plates by its friction alone, to such an extent as to require a force of 5 tons to overcome it. With regard to the revolving of pins, pin bridges were subject to the pins revolving in their holes, more particularly such of them as connected the struts of the web of the girders at the points where those were affected by the alternating reverse strains arising from unequal loading, as in the instance of when the wheels of an engine were between the centre and end of the span, both on approaching and leaving the bridge. This reversing of the strain on those diagonals caused the diagonal to press on the pin in such a manner as to tend to turn it, and did cause it to partly turn under each passing load. This at first would be very slight, but after some time it would wear both pin and hole. The best remedy for this was the adoption of rivetted gusset plates, applied over the pin connection, and so attached that the pins could be removed, thus virtually making it into a rivetted joint.

Mr. J. R. Mosse said that as Director of Public Works in Ceylon he had put up many iron bridges in that Colony. The pin-connected form of bridge was very valuable in foreign countries where transport was very difficult and expensive. A great many road bridges constructed by Messrs. Brotherhood had been put up in the jungle of Ceylon, and of which the several portions, all in small pieces, had to be carried to the site by coolies. Unquestionably, under such circumstances, pin connected bridges were highly advantageous. They were put together by bolts and nuts, and without a single rivet. The spans of these bridges were from 60 to 150 feet, and several of these had three or four spans. That for the jungle all the parts should be small, was a matter of great importance, and all these road bridges in Ceylon gave very satisfactory results. In the early days of the Ceylon Railway many Warren girder bridges were erected, and he had never heard any complaint as to their want of rigidity, though of late years the bridges have always been rivetted. In the construction of the Nami Oya Extension, of which he had charge under Sir Charles Hutton Gregory, Past President Inst. C.E., who was the consulting engineer, all the railway bridges, many of them of large spans, were rivetted, being considered stiffer than pin-connected bridges.

One very satisfactory rivetted bridge was over the Kalutara river, it had twelve spans of 100 feet each, and it was designed for a roadway plus a railway; it was covered with a heavy concrete bed. After some practice, the Ceylon natives did good rivetting, and in some of the bridges this work was done by an hydraulic machine; no difficulty was found in erecting these bridges. Although he had put up pin-connected bridges in Ceylon, as well as rivetted, he regretted that he could not give the difference of cost between the two methods.

Mr. CUNNINGHAM made the following communication in reply, viz.:—Before referring to the criticisms of those who took part in the discussion, the author desires to thank both the chairman and the meeting for the manner in which his paper was received, and to express his gratification at finding that the way in which he had endeavoured to bring the merits of pin-connected bridges before the Society met with very general approval, and with the approval of some who did not concur in his views. He also desires to make two brief explanations. (1) Although the paper was written in the summer of 1887, it was read without alteration, except that the earlier part was curtailed and references were added to some descriptions of bridges which have been published during the last two years. (2) In selecting the forms of steel to be used he would have preferred to substitute channel bars for angles and plates in the top booms and some other parts, but was unable to find suitable sections in the lists of English makers. Such sections could probably have been found in America, where channels are more generally used than here.

The discussion revealed a substantial agreement regarding two points, viz. that pin-connected bridges possess certain qualities, chiefly perhaps facility of erection, which make them well adapted for some localities; and that they are not made in England as cheaply as rivetted ones. The author quite concurs in both these opinions, but thinks it is to be regretted that a kind of structure which is admittedly advantageous in some places, is not made in England as cheaply as other kinds which are not so well adapted to the wants of these localities. Mr. Goodwin and Mr. Findlay referred to some of the causes of this. They stated that English shops have no plant for making eye-bars, and that English workmen are not familiar with pin-connected work. These are doubtless difficulties, but they are not great ones. For the manufacture of pin-connected bridges does not necessarily involve processes which are tedious or expensive. Their rivetted members consist of simple combinations of plates and angle or channel bars, easily bolted together and easily rivetted by ordinary machines. Many hundreds of excellent eye-bars have been die-forged under ordinary steam hammers, and the

necessary turning and boring can be executed with tools such as are found in many English shops. No doubt special plant cheapens the cost of the work, but there need be no great difficulty or expense in executing it with the appliances and men found in most well-equipped establishments. It is certain that pin-connected work which would be quite satisfactory to Mr. Goodwin could be turned out by many English firms, without resorting to the tedious and costly methods of shaping eye-bars and punching through steel bushed templates which he described. If engineers insist on having pin-connected work, no doubt they will get it, and get it at a reasonable price, although at first there may be a little trouble in having it executed properly, owing to its novelty. Many instances might be given in which contractors soon managed to comply with new and improved specifications without extra charge, and no doubt they will soon learn to turn out pin-connected bridges as cheaply as lattice ones, perhaps even cheaper, if engineers demand them. As to the supposed necessity of erecting pin-connected work at the shops, the letter from Mr. Whittemore, appended to this reply, may be referred to.

Several speakers expressed the opinion that pin-connected bridges could not be painted so effectually as rivetted ones. Neither a pin-connected nor a lattice bridge can be properly painted unless it is properly designed; but if the engineer is careful to arrange his plates and bars so as not to leave any crannies inaccessible to the paint brush, either of them can be effectually prevented from rusting. It is not more difficult to do this in the one case than in the other. If "openings expanding under the influence of compressive strain," or "ties which have bulged considerably," are found in any bridge, they indicate grave errors in construction which painting will not remedy.

The author thinks that several remarks must have been made under some misconceptions as to what a modern pin-joint is, and would try to explain this briefly. A modern pin is a truly turned cylinder of iron or steel from $3\frac{1}{2}$ to 8 inches in diameter. The diameter is determined by calculation, so that the pin may be strong enough to resist satisfactorily the bending, shearing, and bearing stresses, which will act upon it. Generally, the bending stresses are far more important than the others, and practically determine the diameters of the pins. These cylindrical pins connect together eye-bars and struts, in the ends of which holes are truly bored to diameters $\frac{1}{32}$ to $\frac{1}{50}$ inch larger than those of the corresponding pins. This allowance is made to facilitate the insertion of the pins into the holes, but a perfectly tight fit is secured in the finished structure, by making a similar allowance in the

lengths of the various members, struts being bored so as to be a trifle too long, and ties so as to be a trifle too short. Members which are sometimes struts and sometimes ties, are comparatively few, and the stresses in them insignificant. If this description of modern pin-joints is kept in mind, it will be understood that notwithstanding the play allowed in boring the holes, the joints do not give or set so as to cause excessive deflection, and that owing to their ample bearing surfaces, the pins do not become indented. As the boring and turning is executed with all the accuracy which can be obtained by the use of machinery, Mr. Sherley Price may be satisfied that the necessity of inserting a pin into such badly fitted holes as he sketched, does not occur. Lastly, if full particulars of the "pin-connections" of Llandovery Bridge had been submitted, it probably would have been found that they are not examples of the kind of pin-connection described by the author, and that their bolts were reduced to the lamentable state shown by Mr. Nursey because the principles just stated were not taken into consideration in designing them.

Two speakers expressed a preference for rivetted connections on the ground that rivets distribute the strains over a larger area, and in a more satisfactory manner than pins. This idea appears at first sight plausible, but very numerous experiments on full sized members have shown conclusively that their full strength is developed by properly designed pin-joints. Many tests of this kind were made by Mr. Eads while he was building the St. Louis Bridge in 1868–74. In 1875 Mr. Bouscaren * tested 34 full sized struts to destruction. In 1877 Mr. Shaler Smith † published the results of experiments made on 111 full sized eye-bars, and described the form and size of head which could be depended upon to ensure fracture taking place in the bar and not in any part of the head. Since then many hundreds of bridge members have been broken in testing machines, and, guided by the results of these experiments, engineers have no difficulty in designing pin-connections which will develop the full strength of either struts or ties. It is known from these repeated trials, that pins may safely be relied on to distribute stress fairly on struts and booms of the forms now usually made. It is not known with anything like the same certainty, that rivets form equally satisfactory connections. The results of many of these experiments are in the hands of private individuals, but some of them may be found in the Transactions of the American Society of Civil Engineers ‡.

* Trans. Am. Soc. C.E., vol. ix., p. 447. † Ibid., vol. vi., p. 263.

‡ Phœnix Bridge Co., vol. xi., p. 1; Monongahela Bridge, vol. xii., p. 365; Christie (small struts), vol. xiii., p. 85; Niagara Bridge, vol. xiv., p. 527; Kentucky and Indiana Bridge, vol. xvii., p. 158; Z-irons, vol. xviii., p. 103; Dagron, vol. xx., p. 254; Cooper, vol. xxi., p. 1; Sibley Bridge, vol. xxi., p. 97.

Mr. Goodwin objected to the statement that a saving might be effected in the secondary bracing of struts by adopting long panels. If the author understands him aright, he contends that a long strut requires more metal to prevent buckling than a short one, and is therefore not so economical, and that struts in pin-connected bridges are so much longer than those in lattice bridges as to bring into play this source of loss. It is undoubtedly true that long struts are not so economical as short ones, because their safe working stress per square inch is much less; but in very many instances the struts of a pin-connected girder would not be longer than those of a lattice girder, or at least not so much longer as to affect their working stresses unfavourably. It may be perceived that this is the case if merely the actual lengths of the struts are considered, but it will be more obvious if it is borne in mind that the lengths of struts must be measured in terms of their diameters. Mr. Goodwin contrasts long struts with short ones, but this comparison is not the only one, nor even the most important one, which the engineer has to make who wishes to ascertain whether a pin-connected bridge is more economical than a lattice one, or whether long panels are more economical than short ones. The main question is not whether a short strut is more economical than a long one, but whether one strut is more economical than several. Or, to put it in another form, a definite amount of load having to be carried to given points, is it better to employ a few big members or a number of small ones? The following considerations appear to point to the conclusion that a few big struts will be more economical than a greater number of smaller ones. 1. A larger diameter can generally be given to a big strut than to a small one, and this means that the metal in the former may generally be subjected to a higher working stress than could be permitted in the latter. 2. If the number of struts is reduced, their sectional areas will be increased, so that even if there is an increase in lengths there may not be any increase in length relatively to diameter. 3. Such secondary bracing as lattice lacing and bearing plates will be much the same in all the struts, whether of large or small area, so that if one can be used instead of two, or even seven instead of nine, a corresponding amount of bracing will be saved. The engineer must take care not to make his struts too long, but he need not necessarily run into this error by reducing their number.

Two indictments were brought against pin-connected bridges which it would be difficult to make good. Mr. Wentworth-Sheilds asserted that they deflected more than rivetted ones. It would be difficult either to prove or disprove this statement by figures, but is it likely to be correct? As a pin-connected

girder is generally deeper than a rivetted one, we may expect that, barring defects of workmanship, it will deflect less, and from the description which has been given of the tight fitting of pin joints I think it will be seen that they are not likely to be a cause of deflection. Mr. Findlay stated that a rivetted bridge does not vibrate to nearly the same extent as a pin-connected one, and that therefore the latter was not so well adapted for fast and heavy traffic as the former. The author thinks that, in order to get at the truth, this statement requires to be made a little more definite. If it refers to bridges under 100 feet span, it is perfectly correct. If it refers to bridges of from 100 to 250 feet span, American practice contradicts it. Probably individual bridges may be found which can be referred to in support of it, but comparatively few of the bridges of this size are of the lattice or rivetted type, and the author is not aware that any difficulty is found in working heavy and fast traffic over the majority of the pin-connected ones. If, however, the statement refers to bridges over 250 feet span, it certainly cannot be substantiated, because lattice bridges are not used for such long spans.* On some large bridges which consist of a succession of very long spans, speeds are, I believe, reduced; but there is nothing to show that lattice bridges would answer better, or that anything would be gained by using them which would compensate for their extra cost. Excessive vibration is a fault which the designer of pin-connected bridges must be on his guard against. At least one eminent authority considers it a common fault, and might probably concur in Mr. Findlay's views, as the letter from Mr. Lindenthal, appended hereto, will show. But these views are not generally held by competent American engineers. It must be remembered that all structures vibrate, and that some vibrate a great deal without bad effects. If the injury caused by vibration is specified, it will probably be easy to devise a remedy, but in the absence of definite charges, it may be well to bear in mind that it is by no means certain that defects caused by vibration would be cured by using rivets instead of pins. These defects may be due to such things as deficiency of secondary bracing in some members, long panels, or light floors; therefore such a simple and useful detail as the pin-joint should not be discarded without full assurance that by so doing some substantial advantage will be gained.

One or two speakers referred to the grip of rivets as an additional element of security which might be obtained by using them. No doubt that is the case, but it is not an element to be depended on. When rivets are contrasted with

* Cooper, Trans. Am. Soc. C.E., vol. xxi., p. 42.

pins, rivets in joints are referred to, and these rivets are generally driven by hand, because they have to be inserted in places which it would be difficult to reach by a portable machine, and because it does not pay to bring out plant and shift it about continually to drive a few rivets scattered about in small groups all over the work. Hand-driven rivets in joints are particularly liable to become loose, and then any benefit which might accrue from their grip disappears.

In reply to Mr. Wilson's question, the author has to state that the effect of brakes was not taken into consideration in either design, but that in either of them it could be easily provided for. As they stand, perhaps the pin-connected one, having steel stringers, would suffer less than the other from the action of brakes.

In the absence of more information than was given, it is impossible to draw sound conclusions from the facts which Mr. Maynard stated as to the weights of a number of spans. It is generally admitted that as far as concerns weight there is a considerable advantage in using pin-connected bridges for spans of 120 feet and upwards. He stated that an 8-inch by 1-inch bar with ends swelled for pins might be said to be 16 to 18 per cent. lighter than a 10-inch by 1-inch plate with ends drilled for rivets. This may be the case if the panels are long, but the saving will be considerably less if they are short. It may be of interest to look into these figures a little. A good basis for comparing them will be the net metal, which in this instance amounts to 8 square inches multiplied by the panel length, and an estimate may be made of the percentage of this quantity which must be added to it, in order to allow for the material required to form the joints. In the plate, Mr. Maynard's 2 inches or 25 per cent. seems a fair allowance for rivet holes. But to make a plate fairly comparable to an eye-bar, an addition must be made to it to represent splices. Ten per cent. will be a moderate allowance for this, so that the total extra material which must be added to the plate is 35 per cent. and it may be assumed that this quantity will be much the same for all panel lengths. Now, as regards the eye-bar, its section through the eye must be 30 to 50 per cent. greater than its section through the body, and a bar having a sectional area of 8 square inches might require two lineal feet to make each head; therefore for the eye-bar the percentage of metal in the heads will be as follows, for given panel lengths:—

Panel lengths, feet	11·4	15	20	25
Percentage of net metal in heads ..	35	26·7	20	16
Percentage of gross metal in plate saved by using eye-bar	0	6	11	14

These figures may at least serve to show that no saving can be effected by using eye-bars in short panels, but that a considerable saving may be effected by using them in long panels, and that, although it may not be so great as Mr. Maynard suggested, still it is not altogether to be despised. The eye-bar boom possesses another element of economy, for it is generally possible to make its sections correspond more closely to the areas required by calculation, than can be done when plates are used.

The prices charged for eye-bars in England are, as Mr. Findlay remarked, higher than there is any real occasion for, so that more ought to be saved by their use than perhaps can be saved just at present. The eye-bar however is only one factor, which in combination with other things, especially long deep panels, causes the economy of pin-connected work.

In conclusion, the author trusts that these remarks may throw some light on the many interesting questions which were raised in the course of the discussion. Three American engineers to whom the substance of the paper was submitted were good enough to favour the author with some remarks on the subject dealt with, and the extracts from their letters which are annexed must be of much interest to all bridge engineers.

From Mr. D. J. WHITTEMORE, Past Pres. Am. Soc. C.E., M. Inst. C.E., Chief Engineer Chicago, Milwaukee, and St. Paul Railway.

"On our older lines of railway in America, originally, the bridges were almost uniformly built of wood, and with the advent of iron bridges, the quick erection of the latter in place of the former, was and is a question of great moment.

"I think it will not be questioned that the pin-connected bridge has fewer and larger parts, hence it follows that shop cost is less than when small sections and many parts are required. It also follows that, by the concentration of stresses on the point or pin, instead of on many points or rivets, the quantity of metal required is more exactly determined.

"I may say that we have no difficulty in having our bridges leave the shops in pieces, each part being made correctly according to the plans. These parts are brought together for the first time at the bridge site. It is not unusual to have certain parts, say the rivetted work, made at one shop, and other parts, such as eye-bars, made at another, 100 or 200 miles away. The finished material is then shipped direct to the bridge site, perhaps 1000 or 1500 miles away, and no trouble is experienced in the erection, each part fitting the other.

"Thus, in erecting the three 400-feet spans of the Kansas City

Bridge, built under my charge as Chief Engineer, the trusses were raised so as to be self-sustaining and free from the false works, in periods of time ranging from about 3 to 5 days for each span after the material was properly delivered and distributed at the bridge approach. How soon this could have been accomplished with a bridge having rivetted connections I cannot say, as I have had no experience in the construction of such spans of this magnitude."

From Mr. C. L. STROBEL, M. Am. Soc. C.E., M. Inst. C.E., Consulting Engineer Keystone Bridge Co.

"I do not think there would generally be so large a difference between the weights of the floor system for the two types, but this will, of course, depend upon the depth allowable for the floor-beams and stringers, and the wheel loads. We have now in this country to deal with very heavy driver loads. 36,000 lbs. on a pair of driver wheels is not infrequent and is sometimes exceeded. Heavy wheel loads, of course, are not favourable for short panels.

"Of late years the tendency in this country has been strongly in favour of long truss panels; 25 feet is frequently used even for short spans, as it is found to be economical. Larger pins are also used than were formerly customary, the best practice being to make their diameter nearly equal the width of chord bars.

"A pin joint seems to us a much more satisfactory mechanical contrivance, especially for the connection of the heavy members of a bridge, than the rivetted joint, for the reason that a pin is a single machine-finished part, to which all the members are attached in as perfect a manner as is mechanically possible. In the case of rivetted joints, it is expected that the same duty will be performed by a number of rivets acting harmoniously, fitted in holes which are not spaced with great accuracy. Furthermore, the efficiency of these rivets is largely dependent on the carefulness of the rivetters, whose work is more or less incapable of control, and field driven rivets, with which we are dealing in this comparison, are always inferior to shop driven rivets for several reasons:—

"1st. They are necessarily driven by hand, whereas the latter are chiefly driven by machine.

"2nd. The men are frequently placed in awkward positions in doing the rivetting in the field, and even the best skill will not always accomplish good results. Inclement weather, of course, also interferes with good work more or less.

"3rd. The men employed in the field are inferior as workmen to those in the shops, and the discipline of the former is inferior to that of the latter. The most rigid supervision and inspection will not always ensure even moderately good work.

"A properly proportioned pin-joint has never given out, while the rivets in a properly proportioned rivetted joint have frequently proven defective so that it was necessary to replace them.

"Pin-connected bridges are holding their own in this country as much as ever. Large spans are never built of any other type. For smaller spans the rivetted lattice type has found favour with a few railroads, solely for the reason that in case a de-railed train runs into the trusses, it is thought there is more likelihood of this type of bridge standing up than the other, but only a very few rivetted lattice bridges are built even for small spans."

From MR. GUSTAV LINDENTHAL, M. AM. SOC. C.E.,
CHIEF ENGINEER LONG SPAN BRIDGE CO.

"Mr. Cunningham's deductions as to the merits of pin-connected versus rivetted bridges, are in the main correct, and coincide with those held by most bridge engineers. But accumulating experience is beginning to modify these views. Rigidity is a quality in bridges not prescribed in specifications, nor is it attainable by any formula or specific construction. The engineer, after having decided on the economical questions, must now take up those of rigidity, and a great deal could be written on that point in favour of rivetted bridges.

"There are two points of view: the commercial, which Mr. Cunningham takes,* and the economical, on the broader ground of greatest rigidity and durability for equal strength and cost.

"Pin-connected bridges have some faults, as we are beginning to see, which rivetted bridges have not, and the question is as far from being settled as ever.

"In my own design I lay great stress on rigidity, whether it is pin-connected or rivetted. My views are very decided on that, though I find it perfectly practicable to get it in pin as well as in rivetted structures, but with modifications from the ordinary routine of details.

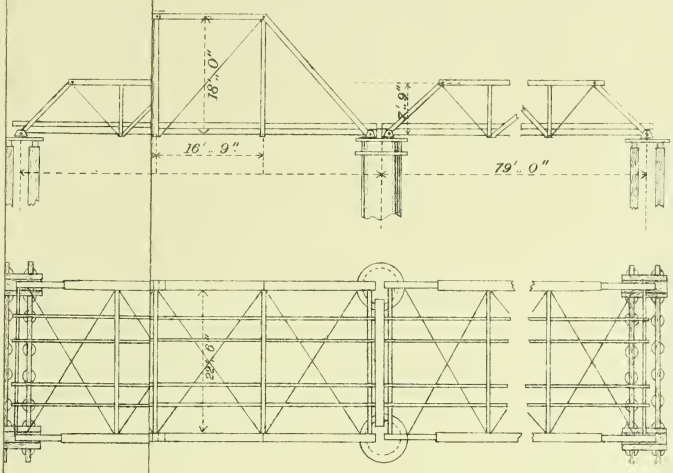
"Much could be said on this head, and had I the time I should take the opportunity of discussing Mr. Cunningham's paper. I have expressed my views in part in a discussion on a paper on Cantilever Bridges (by Mr. Findlay), before the Canadian Society of Civil Engineers. †

"Eighty feet span railroad bridges are now mostly built of solid plate girders. They are heavier than lattice or panel bridges, but just as cheap, because the price per pound is lower, and they are infinitely more durable and more rigid."

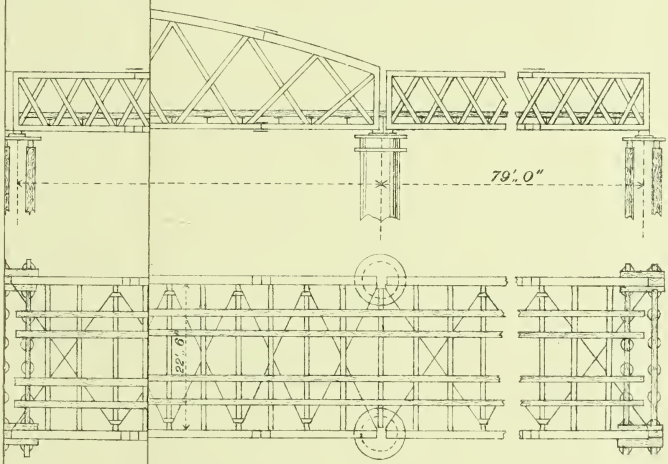
* Perhaps Mr. Lindenthal considers my views more "commercial" than they really are, because the copy of my paper which he was so good as to peruse was much abridged, and did not contain the following sentences (see page 137), "secondary bracing. . . was freely added in both designs wherever it seemed to be required in order to secure durability or stiffness," and "in proportioning the parts of the pin-connected bridge, their various dimensions were fixed with a view to secure excellence rather than economy." These words indicate the lines on which I think the bridge engineer ought to work.—J. H. C.

† Trans. vol. iii., part 1, p. 54.

PLATE Nº I.

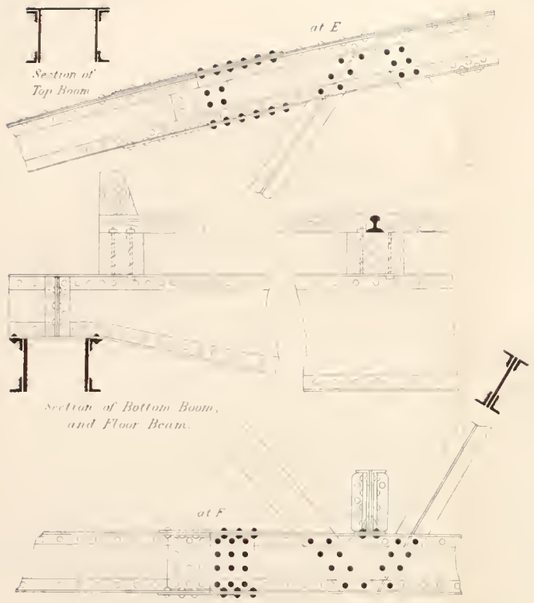


DGE



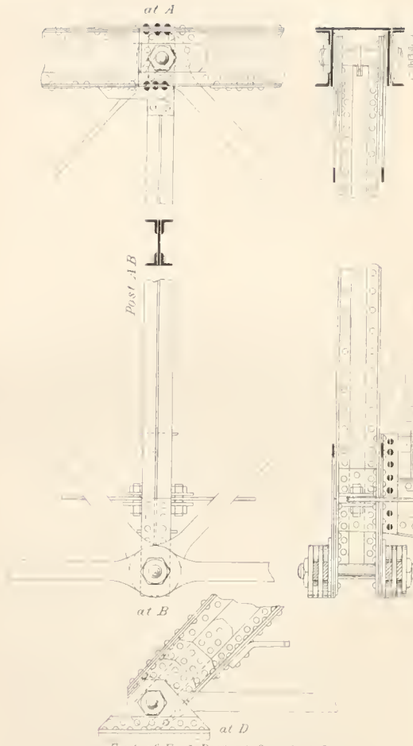
90 110 130 150 Feet

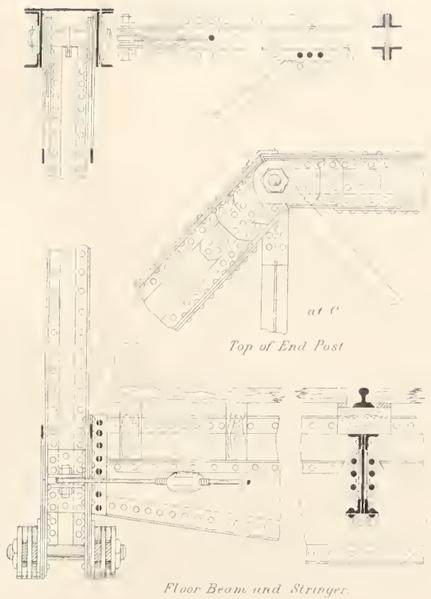
Lith.& Imp. Camb. Sci. Inst Co.



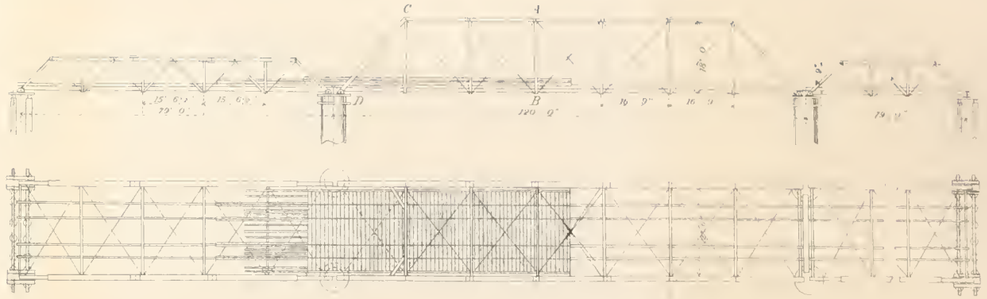
DETAILS OF 120'-0"
RIVETTED SPAN

NOTE *Rivets shown thus* ● *are to be driven in the field*

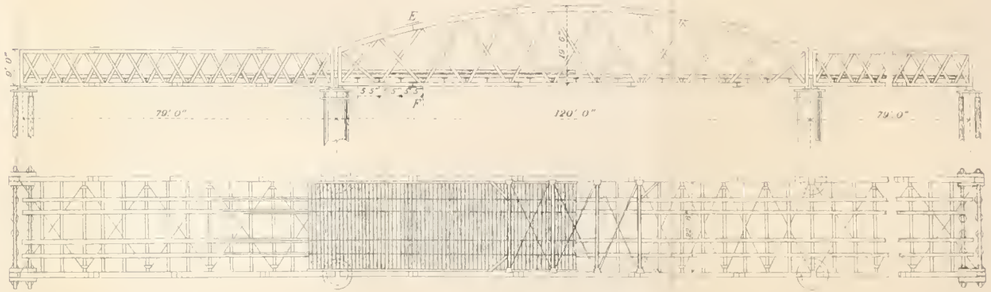




DETAILS OF 120'-0"
PIN-CONNECTED SPAN



PIN-CONNECTED BRIDGE



RIVETTED BRIDGE

Scale 30 F.

November 4th, 1889.

JONATHAN R. BAILLIE, PRESIDENT, IN THE CHAIR.

MODERN GAS-ENGINE PRACTICE.

BY SAMUEL GRIFFIN.

IN the present day, gas motors occupy so strong a position as trustworthy and economical prime movers, that the subject of modern gas-engine practice must prove one full of interest both to the engineer and mechanician. The development of the gas engine during the past ten or twelve years has made such progress as to revolutionise the question of the employment of suitable small motors, and by the successive improvements in its construction, due to the various inventors who have given it their attention, this motor has become firmly established in the high position which it now occupies among the prime movers of the nineteenth century.

What these improvements have been, and in what direction they may be expected to extend, the author proposes briefly to indicate; and in order to clearly illustrate this, it will be convenient to select examples from actual practice, pointing out the more important improvements, as far as possible in the order in which they have been introduced. The author will not occupy the time of the meeting in tracing the earlier history of the gas engine, but will commence with that of Lenoir, first introduced into this country in 1860, that being without doubt the first really successful gas motor.

The engine of Lenoir was in outward appearance very similar to an ordinary horizontal steam engine. The cylinder was closed at each end by a cover, through one of which the piston-rod passed, being connected in the usual way by means of a connecting rod with the crank. On each side of the cylinder was a slide valve, actuated by an excentric on the crank shaft; the function of the one being to admit the explosive charge into either end of the cylinder alternately, while that of the other was to release the products of combustion.

Fig. 1 gives a sectional plan of the cylinder, showing charging and exhaust passages with valves attached, *a* being the induction valve by means of which the supply of air and gas is regulated

in its passage from the ports *b b* in the cover to the interior of the cylinder through the passages *c c*. The valve *d* controls the exhaust as it passes from the cylinder through the passages *e e* into the atmosphere at *f*. The cylinder and covers are entirely surrounded by a water-jacket *g g*, *h h*.

The action of the engine may be described as follows:—At each stroke of the piston the explosive charge was admitted and drawn into the cylinder until about half the stroke was completed. At this point the charge was cut off as rapidly as possible and instantly fired by means of an electric spark from an induction coil. The ignited charge then expanded during the remaining portion of the stroke, doing work upon the piston. The engine being double-acting, received two impulses to every revolution of the crank, precisely as in the case of an ordinary steam engine; and it is worthy of note that with the single exception of the Hugon, as far as the author is aware, no attempt has been made to introduce a double-acting gas engine since that of Lenoir until the Griffin engine made its appearance some three years since.

The principle employed in the Lenoir engine was that known as "Single cycle," all the operations of charging the cylinder, igniting, exploding, and exhausting being comprised in one revolution of the crank shaft, the ignition taking place at constant volume without previous compression of the charge. This constitutes what it may be convenient to denominate Type A; and as large numbers of gas engines of various forms and modifications, but all using precisely the same cycle and method, have since been introduced, in discussing the merits and demerits of the Lenoir, the whole ground occupied by this class of motor will be covered.

The author has already spoken of this engine as being successful. This, however, is only true in a comparative sense, for, although it was capable of doing useful work when in the hands of skilful attendants, yet its consumption of gas per horse-power was so high, and the trouble arising from its delicate electrical igniting arrangements, together with the difficulty of internal lubrication due to high temperature, so great, that, except for very small powers and intermittent work, it was almost useless.

Mons. Tresca, of Paris, found, as a result of a test taken by himself of a Lenoir engine of one-half horse-power, that the consumption of gas was 95 cubic feet per indicated horse-power per hour, or not one-tenth of the thermodynamic value of the gas used; and although in later single-acting engines using the same cycle and method a somewhat better result has been obtained, yet this has arisen rather from an improvement in

the details, based upon a better knowledge of the requirements, than from any improvement in the cycle itself. The best result obtained up to the present time from any engine using this cycle and method, as far as the author is aware, does not fall below a consumption of 80 cubic feet per indicated horse-power per hour.

What are the reasons, then, for so high a consumption, or, in other words, so great a waste of energy? In order to deal clearly with this very important question, it will be convenient at this point to define the theoretical requirements of a gas engine using this particular cycle. The following are the essential points to be aimed at as nearly as possible in practice, viz.:—

(1) During the induction, or charging portion of the stroke, the entering gases should pass freely through a passage of ample area direct into the interior of the cylinder, so that friction, as well as heating by contact with the hot walls of the cylinder passages, may be avoided as far as possible.

(2) The entering charge should be cut off rapidly and instantly ignited, so that no change of volume due to the movement of the piston may take place between the cut-off and ignition.

(3) The ignited charge should be expanded rapidly in actuating the piston, consequently reducing as far as possible the loss of heat through the walls of the cylinder.

(4) The ignited charge should be expanded to the greatest extent before being released from the cylinder, so that the fullest possible amount of work may be obtained from it.

(5) A rapid opening of the exhaust passage, together with large area of the latter should be provided, so that the release may be easy.

There are also other requirements of a minor nature, which it is not necessary to discuss at this point.

The first requirement tabulated is one which need not be dwelt on at any length, inasmuch as the necessity for the provision of charging passages of ample area, so that unnecessary friction or negative work may be avoided, whether in a gas-motor cylinder, steam cylinder, or pump, will be quite understood by those present; but the necessity for the condition which to a large extent arises out of this, viz. that the combustible charge should be as cool as possible at the moment of ignition, will possibly not be so apparent. Indeed, the idea that the combustible charge should be heated, if possible, during or before its entrance into the cylinder is a very prevalent one, and has formed the subject of several patents, but, of course, without resulting in any success. Why, then, should the entering gases not be heated? Because their being heated

expands the charge back upon the atmosphere without doing work upon the piston, and having thus increased their volume by added heat, the initial temperature of explosion is raised without a corresponding increase of pressure. Theoretically, indeed, if it were possible to so heat the entering charge, from any extraneous source, that its temperature would equal that of combustion, under such conditions it would be manifestly impossible to obtain any work due to expansion from it. The conditions necessary for the highest efficiency in regard to the point under consideration, in any gas engine igniting at constant volume, are, highest initial pressure with lowest initial temperature, so that the mean temperature may be low, thus preventing loss through the water-jacket as well as maintaining the efficiency of internal lubrication. Of course, the question of sufficiency of area in the charging and exhaust passages is one which needs attention in any gas motor; on this point the Lenoir had no disadvantages as compared with any subsequent motor. But undue heating of the charge previous to ignition undoubtedly did take place in the cylinder of the Lenoir engine, in consequence of the extreme heat of the piston and covers (probably 800° C.), resulting from the explosions following each other on each side of the piston uninterruptedly during every revolution; and as there was little or no clearance, the entering charge, amounting only to about one-half of the volume of the cylinder, would be brought into immediate contact with these hot surfaces, and thereby to a large extent heated and expanded before ignition. In more recent engines using this same cycle this defect is much modified by the fact of the engines being only single acting, the piston thus running much cooler in consequence of the number of explosions being reduced by one-half, while at the same time its outer surface is exposed to the cooling action of the atmosphere. For the same reason, also, the internal lubrication is more efficient. Improved economy, as well as more efficient working, has thus been secured.

The second requirement, viz. that the entering charge should be cut off as rapidly as possible and instantly ignited, so that no change of volume due to the movement of the piston may take place, is essential to economy for the following reasons:— Rapid cut-off is necessary to prevent wire-drawing of the charge, which is in itself an evil, inasmuch as it absorbs power by creating friction; but a second evil emanates from this, viz. that the charge itself is attenuated. This latter drawback is further increased if the ignition is at all sluggish, in consequence of the rapid movement of the piston further expanding the charge before ignition takes place. A double evil thus ensues, for not only has a certain amount of energy been

absorbed in thus expanding the charge, but what is of still greater moment, the heat lost by expansion has to be made good by the heat of explosion. To put this in another way, the pressure of the charge having been reduced considerably below that of the atmosphere, both by the increased friction of a sluggish cut-off, as well as by the further movement of the piston after the cut-off previous to ignition, an equivalent of heat sufficient to increase the pressure of the charge to atmospheric pressure is necessary before any useful dynamic effect can be produced. The consideration of these evils, which in themselves occasion very serious loss, at once leads to that of another, directly resulting therefrom, and in itself probably of still greater importance, viz., Late Maximum Pressure, and consequently diminished expansion of the charge. It will be well to note also at this point, that late maximum pressure means low maximum pressure, and following as a direct result, comparatively slow as well as insufficient expansion, these two latter being the direct antitheses of the third and fourth requirements tabulated.

The third requirement, viz. that the ignited charge should be expanded as rapidly as possible, is not peculiar to the particular class of motors under consideration; it is equally true of all heat-engines in which the production of energy is accompanied by a fall in temperature of the working fluid or gas; in all such the heat should be converted into work as quickly as possible, in order to avoid undue loss by radiation from the walls of the cylinder. This is, of course, another way of saying that (within certain limits, other things being equal) a high piston speed gives better results than a low one.

The fourth requirement, viz. that the ignited charge should be expanded as far as possible before being released, need not be dwelt on for the moment, as occasion will be taken to return to its consideration later on, in regard to compressing engines. It will be sufficient to notice in passing that in the gas engine, whether compressing or non-compressing, just as in the steam engine, in order to obtain the maximum of economy, a high grade of expansion should be used, and for the same reason, viz. that the greatest possible amount of heat may be converted into work.

The fifth requirement, viz. a rapid and easy release of the exhaust gases, is more important than would at first appear. Of course in gas engines, as in all other kindred motors, it is important to discharge the spent working fluid with as little resistance as possible; but beyond this, in the case of gas engines, and more especially in such as do not discharge the whole of the products of combustion, i. e. compressing engines,

any compression of the hot burnt gases during the exhaust increases the volume remaining in the cylinder, which thus mixes with, and unduly heats, the incoming charge; this, as we have already seen, is a great evil.

The question may now be considered as to what extent the Lenoir engine, together with any others using the same cycle, was capable of meeting the requirements enumerated 1 to 5, thus avoiding the evils already described. It has been shown that the Lenoir drew in its charge until the piston had made about half its stroke, at which point it was cut off by means of an ordinary slide actuated by an excentric. The consideration of this arrangement at once brings under notice one of the great defects of this class of motor, and which renders it quite incapable of meeting the essential requirements of its own cycle. The charge being cut off at the point of maximum piston velocity, the area of the charging passage is gradually reduced by the closing action of the valve at a time when the maximum area is needed, whereby the wire-drawing of the charge, as well as the change of volume due to the action of the piston, of necessity occurs, giving rise to the evils already discussed, these being greatly aggravated by the sluggish movement of the cut-off valve, due to the use of an excentric as well as the employment of an uncertain electrical ignition. In modern engines of this cycle these defects have to some extent been modified by cutting off the charge rather earlier in the stroke, by using a more rapid cut-off worked by a cam, and also a more prompt flame ignition; but still the difficulty to a great extent remains, and is undoubtedly one of the chief factors in the want of economy of this class of gas motor. The expansion of the charge was fairly rapid after maximum pressure was obtained, a considerable proportion being effected during maximum piston velocity, but it is an inherent defect of this type of motor that maximum pressure follows ignition comparatively slowly, in consequence of the rapid movement of the piston at the instant of firing the charge, and as a result of this late maximum pressure, reduced and insufficient expansion of the charge followed. The exhaust being actuated by an excentric and slide, would necessarily be somewhat sluggish as compared with the modern cam arrangement, by means of which almost any desired rapidity of movement may be obtained.

The copy of an indicator diagram, taken from a Lenoir engine (Fig. 2), very clearly sets forth the behaviour of the working charge in the cylinder, this being just what our previous reasoning would lead us to expect. At *a* the admission valve is just beginning to open, the piston also at the same time commencing its forward stroke. At *b* the maximum opening

of the valve has been obtained. From this point it gradually closes until *c* is reached, at which point the charge is entirely cut off, the piston being now at about maximum velocity. At *c* the charge is ignited by an electric spark, the rapid movement of the piston, however, preventing immediate rise of pressure. Maximum pressure is attained at *d*, the charge expanding from this point until the end of the stroke at *e*, at which point the exhaust is opened. It will be seen that from *a* to *b* no appreciable throttling of the entering charge takes place, the piston velocity being low, while maximum area of valve opening is being attained. From this point, however, the order is reversed, the valve gradually closing until *c* is reached, at which point the charge is entirely cut off, the piston being now at maximum velocity. The effect of throttling is here very apparent, the pressure rapidly falling something like 8 or 9 lbs. below the atmospheric line. From the point *c*, at which ignition takes place, the pressure rises to about 60 lbs. at *d*, the piston having travelled at least one-eighth of its entire stroke between ignition and maximum pressure. From *d* the pressure rapidly falls until the end of the stroke at *e*, less than one-half of which is available for expansion of the charge.

Having regard, then, to the foregoing considerations, the defects of this class of motor may be briefly summarised thus:—

(1) The charge was unduly heated previous to ignition.

(2) The action of the cut-off, as well as the ignition, was far too sluggish, having regard to the high corresponding piston velocity.

(3) There was insufficient expansion of the charge after ignition.

(4) There was insufficient and sluggish opening of the exhaust.

To these defects may be mainly traced the want of economy and the inefficiency which are to a greater or less extent the necessary characteristics of all gas engines using this cycle and method.

Following the investigation of this cycle still further, the question arises as to what extent its economy has been improved by the employment of a method more perfectly in harmony with its theoretical requirements. This consideration at once leads to the mention, both in the order of time as well as in the order of improvement, of the "Otto and Langen" free piston, or atmospheric gas engine, and which, considering its very near cyclical kinship with the Lenoir, may for convenience be denominated type B. The advent of this motor, some twenty-four years since, marked a new era in gas engine

practice. It realised to an immensely larger extent than any of its predecessors the theoretical efficiency of the gas consumed, and although somewhat noisy and cumbrous, yet the arrangement of its mechanism was such as not only almost perfectly to fulfil the requirements of its cycle, but also to render it a comparatively reliable machine, even in unskilled hands. With such advantages as these to recommend it, there is no wonder that it should so speedily have entered the domain of sound commercial success.

No doubt most of those present are familiar at least with the outward appearance of this motor. It consisted mainly of a vertical water-jacketed cylinder, in which moved a somewhat heavy piston connected with a long rack in lieu of a piston rod. This rack geared with a wheel, which revolved freely in the direction of the outward travel of the piston, upon a plain horizontal shaft, rotating in bearings on the top of the cylinder, this latter taking the place of the crank shaft of the Lenoir engine and carrying the usual flywheel and driving pulley. By means of an ingenious friction clutch, the toothed wheel instantly, and without perceptible shock, engaged with the shaft on the return motion of the piston. A very clever arrangement of mechanism, consisting of a small countershaft, ratchet, pall, &c., the movement of which was controlled by the governor, gave a small outward travel to the piston when at rest at the bottom of the cylinder, at the same time also actuating the igniting valve, which was situated near the bottom of the cylinder and communicated with its interior below the piston. The operations both of charging as well as exhausting the cylinder were also controlled by the igniting valve.

Fig. 3 is a sectional elevation, which will sufficiently illustrate its general arrangement and construction. *a* the vertical cylinder surrounded by water space *b*. The piston *c* and rack *d* communicate motion to the wheel *e*, this latter, on the return movement of the piston, engaging with the clutch *f*, which is firmly keyed to the main shaft *g*. The governor *h*, by means of the lever *i*, brings the small shaft *j* into gear with the main shaft *g*, thus imparting the necessary movement to the slide-valve *k*, by which all the operations of charging, igniting, and exhausting are controlled.

The cycle of the engine was as follows:—Assuming it to be already in motion at full velocity, the piston would be stationary at the bottom of the cylinder, the countershaft being at the same time released from gear with the main shaft by the action of the governor. Immediately on diminution of the velocity of the main shaft, the governor dropped engaging with the countershaft in gear with the main shaft, and thus by means of

a crank, in contact with a projection at the top of the rack, imparting a prompt but small outward movement to the piston, just sufficient to draw into the space beneath it the necessary inflammable charge through the slide valve. At this point the charge was ignited, imparting a rapid outward velocity to the piston, the momentum of which was absorbed in part by the gravity of the piston itself, and in part by the weight of the atmosphere, which being lifted throughout the whole travel of the piston, commenced to form a partial vacuum beneath it when about half its stroke was accomplished. The piston was thus brought gradually and without shock to a state of rest at the top of the cylinder. At this point the gravity of the piston, together with the added weight of the atmosphere, immediately caused a return downward movement of the piston with an energy theoretically equal to that imparted to it during its outward travel; during the whole of this latter movement of the piston, the rack, through the medium of the clutch, imparted its energy to the main shaft and flywheel; near the end of this stroke the products of combustion were expelled, the piston gradually coming to a state of rest at the bottom of the cylinder. The cycle was thus completed, being renewed at intervals proportional to the work being done by the engine.

From the foregoing brief investigation of the "Otto and Langen" engine, it may be at once seen that, although differing so greatly in structural arrangements as well as method from the Lenoir, yet the cycles were practically identical with each other. Whence, then, its marvellous advance in economy, amounting to something like four times that of Lenoir? In order to answer this most important and interesting question, it may be convenient to rapidly run through its cycle again, and then inquire how far its theoretical requirements were met. During the first portion of one outstroke of the piston, inflammable mixture was drawn into the cylinder behind the piston. Ignition of the charge then took place at constant volume, which expanded, doing work upon the piston during the remaining portion of the stroke. At the next instroke of the piston, the burnt gases were expelled through the exhaust, so completing the cycle. Thus far, then, its cycle is identical with that of Lenoir, and considering it in this manner, we may conveniently for the moment omit dealing with its peculiar method of transmitting its energy, the cycle proper being in no way affected thereby.

It follows, therefore, that the theoretical requirements of the Lenoir, already tabulated, are also precisely those of the Otto and Langen, and if it be found that these were more perfectly met by the arrangement and method of the latter, it will, of

course, confirm the reasoning very satisfactorily. In the first place, then, the entering charge passes freely by a short direct passage into the cylinder, and as the impulses, even at full power, are far less frequent than in the Lenoir, the charge receives less heat from the cylinder and piston previous to ignition. Here, then, at the very outset there is a most important gain, the evils which have already been discussed as the result of undue heating of the charge previous to ignition being to a very large extent avoided. Requirement No. 2 is even still more satisfactorily met. Here there is a distinct motion of the piston specially set apart, as it were, for drawing in the charge; it is moved from a state of rest through a very short distance, and then brought again to a state of rest; consequently, in perfect accord with theory, the cut-off is effected at the period of slowest movement of the piston; immediately on completion of the charge (the piston being at rest), ignition takes place at constant volume, and the outward stroke of the free piston, due to the explosion, being almost instantly completed, requirements No. 3 and 4 are also thus very perfectly met. Expansion is exceedingly rapid, there being nothing to retard the motion of the piston other than its gravity, together with the atmospheric pressure. Expansion also is carried to the fullest possible extent, not to atmospheric pressure merely, but something like 8 or 10 lbs. below it. The whole of the working heat of the charge is thus utilised. As a result of the latter advantage, the fifth requirement is also to a large extent met; the whole of the working heat having been utilised, it follows that the burnt gases which have to be expelled from the cylinder are reduced to the smallest possible volume, and thus ejected with little resistance through the exhaust passages.

Fig. 4 is an enlarged indicator diagram taken from an Otto and Langen engine, a brief investigation of which will at once reveal the reason of its economic success as compared with the Lenoir. The space between the ordinates *a* and *b* represents the short charging stroke of the piston, during the whole of which the induction passage is open, consequently there is no trace of throttling. At *b* prompt ignition (effected by direct flame) takes place, the pressure instantly rising to about 60 lbs. per square inch at *c* without any change of volume. From this point the pressure rapidly falls, doing work upon the piston, the expansion curve crossing the atmospheric line at *d* and continuing by means of the momentum of the rapidly-moving piston as far as the end of the stroke at *e*, at which point the pressure is 10 lbs. below atmosphere. From here, during the return stroke of the piston, the pressure follows the curve *e*, *f*, crossing the atmospheric line again at *f*, at which point the exhaust is opened

and the spent gases released. The lines *d*, *e*, *f* reveal a somewhat curious and interesting phenomenon, viz. decrease of temperature during contraction of volume, the curve *e f* falling considerably below the expansion curve *d e*, instead of being somewhat above it, as might be expected. The reason, however, is quite clear, viz. that the restitution of heat during condensation is less than its absorption by the walls of the cylinder and piston. This loss of heat, however, which in other engines represents an equivalent loss of power, becomes a direct gain in the present case, the lowering of temperature during the return stroke abstracting an equivalent of work on the piston from the atmosphere, the actual gain being comprised in the area *d*, *e*, *f*.

It may thus be seen that in the Otto and Langen free-piston engine a very much closer agreement exists between theory and practice than in the Lenoir or any other engine using the same cycle, while just in the same proportion is found improved efficiency, and were it not for the fact that one great essential of economy, viz. compression, is lacking in this motor, it is the author's firm conviction that, in abstract economy at least, it would have surpassed any compressing engine hitherto constructed.

Having considered the earlier types of this motor, in conclusion, there remains to be reviewed the modern compressing gas engine, which is the most useful and perfect of gas motors.

There is no doubt whatever that the importance of compression previous to ignition was well understood many years before it was made a practical success. Beau de Rochas, a French physicist of great ability, in a work published some twenty-five years ago, very clearly points out the advantages of compression, at the same time describing the cycle by which it could best be accomplished, and it is remarkable that the very cycle thus described is the one which in the hands of Dr. Otto and Messrs. Crossley Brothers has been developed into such a magnificent mechanical and commercial success.

The method employed in the Otto engine is that known as the double cycle. Unlike the motors previously described, which completed their cycle in two movements of the piston, the Otto requires four movements of the piston, corresponding to two revolutions of the crank shaft, and as it comprises all the main essentials of any economical compressing gas engine, an investigation of it will be of interest.

The general appearance and construction of the Otto engine is now so well understood by most practical engineers, that it is quite unnecessary to enter into any detailed description further than is absolutely necessary to illustrate its cycle and theory.

It consists mainly of a single-acting cylinder, in which works a piston connected in the usual way with a crank by means of a connecting rod. At the back of the working cylinder is a clearance space, usually so proportioned that when the entire volume of the sweep of the piston is compressed into it, together with its own volume, a pressure of about 35 to 40 lbs. above that of the atmosphere is obtained. A lay shaft geared with the crank shaft, and revolving at one-half its speed, controls all the operations of admitting, compressing, igniting, and exhausting the working charge, by means of suitable mechanical arrangements which it is unnecessary to describe in detail.

The passage through which the charge is introduced into the cylinder and afterwards ignited, is situated at the extreme end of the clearance space farthest from the piston, the exhaust being usually discharged through a passage situated at about the centre of the compression space.

Its action is as follows:—During the first outstroke of the piston, an explosive charge of air and gas is drawn into the cylinder through the charging passage, commingling with the air or products of combustion already contained in the clearance space. During the following instroke (the charging passage being now closed), the explosive charge is compressed into the clearance space and ignited at about the commencement of the next outstroke, during which the burning charge expands, doing work upon the piston. Just before the completion of this stroke the exhaust valve is opened and the burnt gases are expelled during the next instroke. The cycle is now completed.

From the foregoing brief description it may be seen that, unlike either of the previously described motors, the Otto devotes one entire outstroke of the piston to the operation of charging the cylinder, which charge is afterwards compressed to about one-third its original volume, then ignited, and expanded again to its original volume previous to compression, the differences between the mean pressure of the compressing stroke and that of the expansion or power stroke constituting the nett available indicated power. The theoretical requirements of the Otto or other compressing class of gas motors, does not differ materially from those of the Lenoir or non-compressing gas motor. Like these it ignites at constant volume and needs ample charging and exhaust passages, rapid cut-off of the entering charge, prompt ignition, rapid and full expansion of the burning charge, and easy discharge of the burnt gases.

All that has already been said on these and similar points in our investigation of the Lenoir engine, holds equally good in regard to the engine now under consideration; nor is it to any very marked superiority in any of these points that the great

efficiency of the Otto is to be traced. Compression of the charge previous to ignition is the great principle which underlies and determines its operation, and to which alone, coupled with sound mechanical arrangements, its economic success is due. This is of course equally true of all modern compressing gas engines; without compression, economy combined with a reasonably small capacity of working cylinder is impossible.

It may, therefore, be profitable to devote a few moments to the investigation of this very important point, seeing that it plays so vital a part in the modern gas engine. In the first place, compression enables a greater weight or mass of air to be reduced to a given volume in the explosion chamber of a gas engine previous to ignition than could be in any other way accomplished, the effect of this being to absorb a greater amount of heat from a given quantity of burning gas, than could be absorbed by the same volume of air at atmospheric pressure merely. Now, according to the law of thermodynamics, "heat and mechanical energy are mutually convertible," it follows, therefore, that the greater the quantity of heat absorbed and utilised by the working charge, the greater the resultant mechanical energy, and this is exactly what happens with the compressed charge. Taking a given volume of air at atmospheric pressure, diluted with, say, about $\frac{1}{10}$th its volume of carburetted hydrogen, and exploded in an ordinary non-compressing gas engine cylinder, this would give a maximum pressure of about 50 lbs. above atmosphere, while a more highly diluted charge compressed to equal volume at say 40 lbs. above atmosphere, and exploded in the ordinary way in a compressing gas engine, would give a maximum pressure of no less than 150 or 160 lbs. per square inch. It is, however, not merely in the enhanced initial pressure thus obtained that the great gain in compression consists; but that, in addition, the large amount of heat absorbed and stored, so to speak, in the dense mass of compressed air, is competent to sustain the expansion curve of the indicator diagram fully up to the adiabatic line, thus giving a mean pressure, averaging from 60 to 70 lbs. per square inch, this being considerably in excess of the initial pressure even of ordinary non-compressing engines.

The enlarged copy of indicator diagram (Fig. 5) taken from an Otto engine of 7 horse-power, very graphically sets forth the value of compression. The atmospheric line *a, b*, indicates the charging stroke of the piston, at *b* compression commences and continues until the return stroke is completed at *c*, at which point the pressure is about 40 lbs. above that of the atmosphere. Ignition of the charge now takes place, raising

the pressure to 196 lbs. per square inch at *d*, from which point expansion commences and continues as far as *e*, where the exhaust is opened and the spent charge released. The expansion curve *d e* represents the working or power-stroke, and is almost perfectly adiabatic, the resultant mean pressure being no less than 70 lbs. per square inch.

Herein then lies the great value of compression, in that it enables a large amount of heat to be utilised and converted into work which without its aid must of necessity pass away through the walls of the cylinder and exhaust. At the same time, in consequence of the much higher pressure thus obtained, much smaller cylinders, with less cooling surfaces, are needed to develop a given power.

The cycle of the Otto engine is also a very perfect one for carrying out the principle of compression; firstly, because the various operations of charging, compressing, and exploding, are completed in a single cylinder, thus avoiding the extra cost and friction of displacers or compressing pumps, together with the friction and loss of separate charging chambers and passages; and, secondly, because the main requirements of the cycle itself are very perfectly met. There are, however, two objections to be urged against this cycle and method, to the removal of which a number of able inventors have given their attention.

The first objection is that of cyclical variation and insufficient development of power for any given size of engine, due to the fact that only one impulse is obtained in two revolutions of the crank at full power; the second objection being that of insufficient expansion of the burning charge, this being only carried to its original volume before compression. It must be admitted that both these objections appear valid from an engineer's point of view, and as an improvement in either of these directions would undoubtedly denote progress, they are well worthy of consideration.

As far as the author is aware, the first commercially successful compressing gas motor, in which an impulse was given to the crank at every revolution, was that of Mr. Dugald Clerk, and known as the "Clerk" gas engine. In general appearance this engine somewhat resembled an Otto, having a single-acting cylinder, but with the addition of a pump or displacer by its side, the piston of which was actuated by a connecting rod worked from a pin in the flywheel. The position of this pin was one-fourth of a revolution in advance of the main crank. A passage from the back of the displacer terminated between two ordinary mitre lift-valves, through the lower one of which the combustible charge was drawn into the displacer during its out-stroke and afterwards discharged through the upper one on

its return stroke, through a passage into the back of the motor cylinder. Near the front end of this cylinder was an annular passage, which was uncovered by the piston just about the finish of its outstroke, through which the burnt gases were discharged.

Briefly, the action of the engine was as follows :—During the first portion of the outstroke of the displacer piston, the explosive mixture was drawn in, being then followed by air during the latter portion of the stroke. On the return stroke its contents were discharged into the motor cylinder, the air sweeping out the products of combustion through the exhaust passage in the front, which was then covered by the return of the motor piston, the further movement of which afterwards compressed the explosive charge, ignition taking place at the commencement of the next outstroke. The whole cycle was thus completed in one revolution of the crank.

The gain from this arrangement must, however, in justice be acknowledged to be far more apparent than real. It was steadier than the Otto when at full power only; at intermediate powers it was less steady, while the difficulty of governing was much increased by its peculiar method of charging. In point of economy, no doubt, a diagram from this motor's cylinder would compare favourably with the Otto, but allowance had to be made for a certain amount of lost compression in the displacer, as well as negative work in charging, due to the automatic action of the valves and friction in the extra long passages. Making these deductions from the motor diagram, the nett indicated efficiency must necessarily fall considerably below either that of the Otto or any good compressing engine completing its circle within the motor cylinder. Other compressing engines, which need not here be particularised, using practically the same cycle under still more unfavourable conditions, have been from time to time introduced, but the same radical defects underlie them all, viz. increased complication of working parts, together with increased negative work in completing the cycle. These latter disadvantages far more than counterbalance any small gain in cyclical uniformity or decreased dimensions of motor cylinder thus obtained. No doubt cyclical uniformity is a point to be gained, nor is the objection on this ground to the ordinary two-cycle single-acting engine made without just cause, but this advantage must not be obtained at the sacrifice of other equally or even more important points.

It was mainly with this object in view, viz. to obtain cyclical uniformity, and at the same time utilise the unused end of the ordinary single-acting motor cylinder, that the author commenced his experiments some five years since, with a view to constructing a double-acting gas engine, the fundamental

principle laid down at the onset being that the whole cycle must be completed in the motor cylinder itself, for the reasons already given. It was, however, soon evident on reflection that the ordinary double cycle could not be employed for this purpose, for the simple reason that in a double-acting cylinder so constructed two impulses must follow each other in one revolution of the crank shaft, these being again followed by an entire revolution without any impulse even at full power. Such an arrangement would, of course, be quite inadmissible, the irregularity of period between the impulses would undoubtedly produce even greater cyclical variation than in the single-acting engine. In view of these facts, the triple cycle at once suggested itself as being the best and indeed the only one which met the requirements of such an engine. Firstly, because it gives equal periods between the impulses, alternately at each end of the cylinder, at the same time admitting of the maximum number of impulses possible in a double-acting cylinder completing a compressing circle within itself, viz. two impulses in three revolutions, i.e. one impulse in each one and a-half revolutions. Secondly, because it enables a charge of cold air to be passed through the cylinder and passages after each impulse, even at full power, thus very materially cooling the interior by expelling the hot products of combustion and thereby keeping down the temperature of the charge previous to ignition.

Several decided advantages appear to be special to this engine, viz. (1) For a given size and weight of motor there is a gain of one-third in power over an ordinary double cycle engine; (2) absolute freedom from cyclical variation; (3) entire absence of undue heating in the cylinder, due to the fact that the impulses are distributed between two separate combustion chambers, together with the entire removal of the heated products of combustion. There were, of course, many practical difficulties to be overcome, such, for instance, as undue heating of the piston rod, passing as it does through the centre of the burning charge; efficient lubrication of the interior of the cylinder, the oil having to be introduced against pressure without allowing any of the burnt gases to escape into the supply of oil in the lubricator, &c. These, and other difficulties of a like nature, have, by patience and perseverance, been gradually overcome, and it gives the author great pleasure, in touching on these points, to acknowledge the valuable services of Messrs. Dick, Kerr, and Co., the licensees and manufacturers of the "Griffin" engine.

The enlarged copy of indicator diagram (Fig. 6), taken from a 12 horse-power nominal double-acting "Griffin" gas engine

exhibits all the essential characteristics of Fig. 5, having, however, the special feature of double action, together with large areas, the expansion curve being well-sustained throughout.

The following are the particulars of the test:—Cylinder, 11-inch bore by 16-inch stroke; speed, 180 revolutions per minute; indicated H.P., 28·7; brake H.P., 23; gas per 1 H.P. per hour, 17·7 cubic feet; gas per brake H.P., 22·17 cubic feet; consumption of gas running light, 78 cubic feet per hour. In this test, Kilmarnock gas was used, the heating power of which is from 4 to 5 per cent. higher than that of London gas.

Turning now to the second objection to the ordinary two-cycle engine, viz. as to its insufficiency of expansion, it is evident that for a very considerable time this apparent effect has been understood and various remedies proposed. Mr. Dugald Clerk, in his work on the Gas Engine, published in 1886, very clearly points it out, and states that he himself had been engaged in experiments with a view to improvement in this direction. Messrs. Crossley Brothers, if the author has been correctly informed, have also experimented on various methods of improvement. Mr. Atkinson also has introduced two engines in which increased expansion has been accomplished; and lastly the author himself (no doubt among many others) has been working in the same direction, the labours of the latter having resulted in a patent being taken out about eighteen months since for a method of obtaining increased expansion in gas motor cylinders. So far this has not passed beyond the experimental stage; at the present time, however, one of the author's "Twin" engines with this expansion gear attached is being built. When completed, the arrangement will be thoroughly tested in practice.

The gear itself is very simple; it is applicable to almost any arrangement of engine, and admits of any workable grade of expansion being used. It consists merely in the application of a rapid cut-off valve, actuated by a cam through which the charge passes into the cylinder. This valve and cam is so arranged as to cut the charge completely off at any given point in the charging stroke, the remaining portion of the stroke being completed with a partial vacuum in the cylinder. This partial vacuum, however, theoretically causes no loss, the atmosphere restoring all the energy spent in lifting it during the return or compressing stroke, compression of course commencing at the same point of the stroke as that at which the cut-off is effected. By this arrangement, expansion of the working charge is readily carried to any volume beyond that occupied by it at ordinary atmospheric pressure previous to compression, this being governed solely by the point of cut-off.

Fig. 7 gives a horizontal section of the experimental gas engine cylinder fitted with the cut-off valve, the ordinary double cycle being employed. The charge is introduced into the cylinder *a*, through the valve *b*, which is adjusted to close rapidly at any given point in the charging stroke of the piston according to the desired grade of expansion. The three indicator diagrams 8, 9, 10, correspond with the three points of cut-off *a*, *b*, *c*, and represent respectively $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, of the stroke. Referring to diagram 9, the charge is drawn into the cylinder along the atmospheric line *a*, *b*, *c*, as far as *b*, at which point it is cut off, the remaining portion of the stroke of the piston causing the pressure to gradually fall to about 6 lbs. below that of the atmosphere at *d*. The return stroke of the piston at this point commences to compress the charge along the curve *d e*, crossing the atmospheric line at *b*, the point of previous cut-off. At *e*, the charge being compressed to about 40 lbs. above atmosphere, ignition is effected, the pressure rising to 150 lbs. at *f*, from which point expansion takes place, the burnt charge being released at *g* at about 12 lbs. above the pressure of the atmosphere. Diagram (Fig. 8) is taken with a higher grade of expansion ($\frac{1}{3}$rd), the mean terminal pressure being correspondingly lower, while that of diagram (Fig. 10) taken at a lower grade ($\frac{2}{3}$rds) is correspondingly higher. The gain in indicated efficiency under the most favourable conditions amounts to about 5 per cent. over expansion to full volume in the ordinary way, the output of power being of course proportionately less.

Mr. Atkinson, in his cycle engine, has obtained the same result by means of a totally different mechanical arrangement. Here a novel system of jointed levers produce four distinct motions of the piston in a single-acting cylinder during one revolution of the crank, each stroke varying in length of travel. The first, or charging stroke equals about $\frac{1}{2}$ the working or power-stroke, the second or compressing-stroke being about $\frac{1}{6}$ less. Space is thus left to contain the compressed charge, the third outward or working stroke is completed at high piston velocity, being followed by the fourth back stroke by which all products of combustion are expelled. In the author's opinion the cycle thus employed in the cylinder for the purpose of obtaining increased expansion is a very perfect one. Hereby there is an expansion of the working charge to nearly double its volume previous to compression, with the further advantage of rapid expansion due to high piston velocity. The fullest economic advantage may therefore be reasonably expected from this arrangement.

Fig. 11 is a large copy of indicator diagram taken from

Mr. Atkinson's cycle engine. It will be seen at once that it bears a very strong resemblance to those taken from the author's expansion engine, the vacuum line of course being absent. The efficiency is almost identical with Fig. 8, the expansion in both cases being carried to about double the volume previous to compression.

The practical results, however, are at best disappointing as compared with those which theory would lead us to expect, and most certainly would not warrant the introduction of the slightest complication in detail for the purpose of obtaining them. Taking the best published results, we find the gain to be less than three per cent. in economy as compared with an ordinary two or three cycle engine working under normal conditions, and expanding its working charge to original volume before compression, while at the same time there is the practical disadvantage of greatly increased bulk and weight for a given power.

The author's experiments with his expansion engine up to the present time very fully corroborate these facts, having already led him to the conclusion that expansion beyond that of the ordinary compressing cycle is of very doubtful commercial value, for in whatever way obtained it must add more or less to the complication of the engine, at the same time greatly increasing the bulk for a given output of power. The resultant economic gain is at best but very small in amount.

The author has been informed that for exactly the same practical reasons, Messrs. Crossley Brothers have long since abandoned the idea of further expansion in their ordinary Otto engine, having since turned their attention to compounding with a view to greater economy; but in the author's opinion, such a system as applied to gas engines, although right in theory, must fail for practical reasons, the chief one being the low specific heat of the working charge.

There are many other interesting and important points of detail in connection with modern gas-engine practice which in themselves would far more than furnish subject matter for an entire paper devoted to their consideration, and to the preparation of which at some future time, should it appear desirable to this Society, the author would have much pleasure in devoting himself. A bare enumeration of these, however, must suffice at present, there being, 1st, the question of various modes of ignition at present known, their possible development, and their bearing upon the practical success of the gas engine; 2nd, the very important question of governing, both by intermittent and regular impulses; 3rd, the question of design in relation

to cycle, proportion of cylinder, and degrees of compression employed; 4th, the behaviour of the working charge in the cylinder in relation to temperature, lubricating, &c.; together with many others of minor interest.

It is of course quite impossible within the limits of a paper such as this to do more than touch the mere fringe of a subject embracing so wide a field as that implied in "Modern Gas-Engine Practice." The author trusts, however, that sufficient has been said to render intelligible the nature of some of the more important developments through which the gas engine has passed, as well as the theory upon which such are based. No doubt very much still remains to be done in the way of development and improvement in detail; but in the author's opinion the cycle and method of the best gas engines of the present day are those which will determine the gas engine of the future. No doubt much remains to be done in the development of methods of utilising the vapour of petroleum as a fuel for gas engines. The injection of any liquid hydrocarbon into the motor cylinder, or even the employment of the unpurified vapour or gas itself, can never become commercially successful; the difficulties of ignition as well as the abnormal deposit of tar and bye-products in the motor cylinder are far too serious to admit of this. What is needed to-day is a simple portable apparatus by means of which a fairly pure gas can be generated from cheap crude hydrocarbon oils. Such an apparatus would greatly extend the field of operation of the gas engine, by rendering it not only portable but also independent of any permanent gas supply. No doubt water gas is destined to play an important part in the near future as fuel, especially for the larger sizes of gas engines. The high price of ordinary carburetted hydrogen has hitherto been the chief obstacle in the way of the introduction of anything beyond about 50 indicated horse-power. Given, however, a gas of any kind capable of developing an equivalent of heat in a gas motor, at say, one-half the cost of ordinary gas, and there will certainly be no practical difficulty in the way of building gas engines of two or three hundred horse-power to fairly compete with steam. But when all has been done which can be done, in this and other directions, it is certain that except within comparatively limited spheres, the gas engine and steam engine can never be real competitors; beyond these limits, their claims do not overlap, but are rather complementary one to another, each occupying a domain peculiarly its own. That our vast Atlantic liners or floating batteries, our swift railway trains or colossal mills, will ever be propelled or actuated by motors using gas as a fuel in their cylinders, is, in the author's opinion, beyond the limits of

probability. To meet requirements such as these, the steam engine, with its extreme simplicity, portability, and almost unlimited concentration of energy, is alone capable. But, on the other hand, among the multitudinous requirements of daily social and commercial, and even domestic life, the gas engine, by virtue of its cleanliness, economy, safety, and general adaptability, holds unchallenged and increasing sway.

DISCUSSION.

On the motion of the PRESIDENT, a vote of thanks to Mr. Griffin for his paper was unanimously passed.

Mr. ARTHUR RIGG said that all must agree that the paper was a very interesting and lucid exposition of the history of the gas engine, and it would have been an advantage if they could have had more details of Mr. Griffin's latest invention. This history was an example of the correct application of theory to practical work; and, as a result of the combination, they had at last got the engine into a very perfect condition.

After so much had been heard of the approaching end of the steam engine, it was very comforting that an exponent of gas engines should tell them that there is still a future for the former.

The diagrams which had been exhibited had all a wonderful family likeness. The point that struck him in the first one shown was the use of slide-valves, which Mr. Griffin in his later experimental engine had abandoned altogether, as it appeared to be an unmixed advantage to get rid of such valves in connection with the gas engine, because of a deposit from the gas, which was more or less destructive to their surfaces. The original gas engine had long passages and a great amount of heating surface, which corresponded to some extent with the cooling influence of long passages in steam engines, and it might be said that the two engines ran together on somewhat similar lines. There was much still left for gas engineers to do; one improvement of the first importance to be looked for being to get rid of the present unsteady running, which was usually due to there being only one impulse in two revolutions; also double fly-wheels with long belts would tend to get rid of the unsteadiness, which was of especially serious importance in connection with dynamos; besides this, the working of gas engines was often very noisy.

The pressures used had increased most enormously, and the smaller engines now seemed to work at much higher speeds than formerly. It was perfectly obvious that the increase of

speed would be a very important point in the economy and success of the gas engine.

Mr. JAMES ATKINSON said he did not think that any body could have stated more ably than the author the essential points of the A type of gas engine, and of course those essential points to a very great extent belonged to all the other types. He (Mr. Atkinson) agreed with the author as to these requirements. For instance, he had mentioned the wire-drawing of the incoming charge. In the engines of the A type, (which he (Mr. Atkinson) had made some years ago, the main portion of the charge was admitted by a slide-valve; the piston passed a passage and opened a self-acting inward-opening valve, which was closed by the ignition, so that the suction line was practically uniform with the atmospheric line up to the point of ignition; that, of course, made a very great improvement in the economy. Again, the exhaust valve was opened by the main valve tapping it open at the end of its stroke, and it was closed by the main valve again tapping it downwards, thus giving a perfectly free exhaust. As the result of those improvements in the Lenoir type of engine, they had numerous engines which gave a brake horse-power of 76 cubic feet of London gas in the smaller sizes, to 65 cubic feet in the larger sizes. He believed that at the present moment there were about 150 of those engines working very satisfactorily in London. They were noisy, and, of course, a consumption of 76 to 65 cubic feet of gas per horse-power would not compare with what had been done later on. He agreed with the high encomium which the author had passed upon the Otto engine; he believed that the mechanical production of that engine was mainly due to Messrs. Crossley Brothers, of Manchester, and that it might be claimed more as a national engine than a German engine. In connection with continued expansion, there were one or two points which perhaps Mr. Griffin had not clearly laid before them; for instance, the Otto engine, when it opened the exhaust, was at a pressure of about 30 or 35 lbs. in the cylinder, and it was of little use to complicate an engine with a view to procuring expansion much beyond that amount; that pressure was due to the cooling which took place in the charge up to that point. In the differential engine, which was practically the same in theory as the cycle engine, comparing the Otto with one of his engines running at the same speed, the expansion up to the point of original expansion was done in one-fourth the time; the result being that he generally got from 7 to 10 lbs. higher pressure than the original volume at the point of expansion. It was favourable to an expansion engine to have an extra 10 lbs. pressure to expand with; as the result would be that expansion could be carried to double the volume, and there

would still be 14 or 15 lbs. in the cylinder. If there were only 30 lbs. it would be of comparatively little use to continue the expansion beyond that point. He did not think that effective power could be obtained from any engine with less than 10 lbs. effective working pressure, and it was of no use to expand beyond 10 lbs. in the cylinder. Mr. Griffin obtained continued expansion by cutting off at point *b*. and then expanding below the pressure of the atmosphere. There were two evils in this method. In the first place, whatever temperature the gases were at in the cylinder at the point *b*, the expansion below the atmosphere would reduce the temperature, and as a natural result the charge must be raised to a very considerable degree of heat during the time it was travelling from *b* to *d* and back again from *d* to *b*. But it had been clearly explained that it was essential to keep the charge as cool as possible before and during compression, therefore he was afraid that the considerable amount of heat thus acquired would seriously militate against the commercial and the theoretical efficiency of the engine in that respect. Again, the piston in travelling from *b* to *d* and back from *d* to *b* was doing negative work. Adding the negative piston travel during the scavengering revolution in Mr. Griffin's engine, and comparing it with his (Mr. Atkinson's), it might be said that the piston of the former had to travel twice as far to do the same work. He found in the differential engine that this was one of the main causes of its not being so satisfactory an engine as the cycle. He had two pistons in the differential, and they had to travel a greater number of piston feet than was necessary for actual work. In the cycle engine the piston travelled only such distances as were necessary to do the work, and he obtained the same end as the scavengering charge by driving out the whole of the contents of the cylinder. With regard to the diagram of the cycle exhibited by Mr. Griffin, it required correction in so far as that the atmospheric line needed to be extended beyond the point of compression. As to the weight of his engine, to which allusion had been made in the paper, he found that it was about the same as that of the Crossley. In the smaller sizes it was very much lighter, and took up less room. He entirely agreed with the remarks of Mr. Griffin as to petroleum engines; he thought that the only way to work petroleum successfully in a gas engine was to convert it into a permanent gas before using it in the engine.

Mr. Ridealgh said that he thought that there was a great waste of power in Mr. Griffin's engine through its having to make so many revolutions before it got the power; and, further, the engine appeared to be a very complicated one. He knew of a gas engine which registered 600 impulses a minute.

Mr. John Kerr said that the author had spoken in a very

fair way of the comparative merits of the various types of gas engines. What he (Mr. Kerr) had to do with principally was the commercial question, and therefore it was difficult for him to speak upon the subject. He might, however, say that in his opinion it was almost harder to make an engine a commercial success than to invent an engine; but he felt well assured of the commercial success of the "Griffin" engine, with which he was connected.

Mr. Geo. Eraut, Jun., said that he came rather as the representative of Mr. Jabez Church than to speak for himself. At one of the waterworks under Mr. Church's charge, a steam engine was used to raise the water for the supply of the district. Owing to the continuous increase in the number of consumers, it became necessary, some two or three years since, to obtain an additional supply of water, and it was decided to use an "Otto" gas engine for the motive power at the new station. The height of lift and the friction due to length of rising main were about the same for the new pumps as for those driven by the steam engine, so that by putting the whole of the pumping upon one station at the time, it became possible to compare the relative cost of performing a certain amount of work by either motive power.

The trials were first carried out for periods of one week each; some time later on they were repeated, being then continued for periods of one month each; and though the total quantity pumped, and the heights to which portions of the quantity had to be lifted, would probably vary considerably from day to day, still, considering the long periods over which the trials were spread, there is no room for supposing that the results obtained were not a fair average.

The unit employed was actual cost of labour, materials, and stores per 1000 gallons pumped, no allowance being made for interest on capital outlay or for depreciation.

As a result of the trials, it was found that with the steam engine the cost of pumping 1000 gallons to the district was $3\frac{1}{4}d.$, and with the gas engine using town gas at 4*s.* 3*d.* per 1000 cubic feet the cost was 3*d.* per 1000 gallons.

The price of the town gas being considered very high, it was suggested that the fuel account for the gas engine might be reduced by adopting the Dowson process for manufacture of gas. An order for a suitable plant was accordingly placed in Messrs. Crossley's hands, and when completed further trials were made with the gas engine.

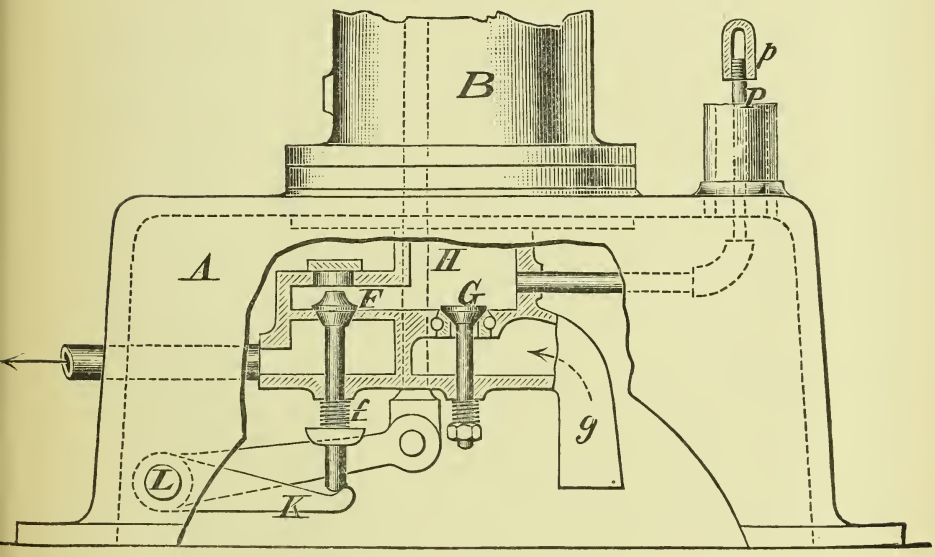
It was found that by using Dowson gas the cost of pumping 1000 gallons of water by the gas engine was reduced to 1*d.* (one penny). This cost included the same items as previously men-

tioned, and also the necessary town gas for the side-light for firing the charge.

A previous speaker has stated that "in his opinion we may look to 'Producer' or 'Water' gas to assist in carrying out the greater portion of those economies in working which yet remain to be made before the gas engine can be considered practically perfect."

The Dowson gas is certainly a "producer" gas, and the economy effected by its use tends to confirm the opinion of the speaker above mentioned, and gives ground to hope that the advance made in this direction may in the future be further improved.

Mr. Perry F. Nursey said there could be no question that the simpler the construction of a gas engine, and the fewer its parts, the better would be the results of its working, other things of course being equal. He had lately had to examine into the working of a very simple and direct-acting gas engine, of which the following diagram shows the valve arrangement.



This was a very economical motor, and was known as the Purnell engine, the special features in which were that there was no ignition valve, and the admission valve was automatic. Mr. Nursey gave a description of the engine as follows:—

The engine comprises a box-base A, upon which is a vertical cylinder B, which is open at the top and is surrounded with a

water casing. The cylinder has a trunk piston connected to the crank on the flywheel shaft, which is mounted in overhead bearings carried in brackets extending up from, and in one piece with, the cylinder. In the base are two valves F and G, both opening upwards to a space H in free communication with the interior of the cylinder. The valve F is kept closed by a spring *f*, and is opened to discharge the exhaust by an arm K of a rocking shaft L, which is connected with the flywheel shaft. The valve G is self-acting, and opens to admit air by the pipe *g*; it has a hollow seating, the annular cavity of which is connected with a gas supply pipe and has numerous small perforations opening to the face of the valve seating. From the space H a passage leads to a vertical pipe P, which is kept heated by a gas burner, and which has a cap *p* that can be screwed more or less down so as to diminish or increase the interior capacity of the pipe P. The action of the engine is as follows:—As the piston ascends, the self-acting valve G rises, admitting air mixed with gas into the space below the piston, the exhaust valve F remaining closed. The piston in descending compresses the gaseous mixture, and when the pressure is sufficient a portion of the mixture is forced into the heated pipe and becomes ignited. The ignition is communicated to the charge in the cylinder, and the piston is propelled upwards. During the subsequent descent of the piston, the exhaust valve F is opened and the products of combustion are expelled. By adjusting the cap on the heated pipe P, which after each ignition remains charged with products of combustion, the volume of the products contained in the pipe can be so regulated that their compression to the extent necessary to secure ignition of the cylinder charge takes place just as the piston reaches the end of its compressing stroke, thus dispensing with valve gear such as is usually employed to put the igniting apparatus in communication with the charge. Mr. Nursey stated that he had seen several of these engines run. One of them, of 1 horse-power nominal, developed $1\frac{3}{4}$ horse-power on the brake with a consumption of 36 cubic feet of gas per hour. He put one to drive a band saw, a wood-turning lathe, a drilling machine, a metal-turning lathe, and a grindstone, at one and the same time. The machines, however, were not all in use simultaneously.

Mr. Atkinson said that he differed from Mr. Griffin and Mr. Nursey in their opinion that gas engines would not be adopted for very high powers. It was his firm conviction that they would be brought into use, not only for driving mills, but for various purposes of that kind.

Mr. Griffin said that if Mr. Purnell had been present, he

should have been very glad to hear him state the difference between his engine and the Otto engine, for he (Mr. Griffin) could see no difference whatever in principle or cycle.

Mr. Atkinson said that the only difference was that in the Otto the suction valve was lifted definitely.

Mr. Griffin, in reply, said that that was a question of detail. He thought that whatever theoretic economy might be claimed for the Otto might be claimed for Mr. Purnell's engine, both engines being identical in principle. The latter had the incandescent tube ignition; the charge was introduced through a mitre valve, and the exhaust also ejected through a mitre valve, just as in the latest type of Otto engine. Coming to Mr. Atkinson's remarks as to the expanding charge, he understood him to refer to the absorption of heat from the walls of the cylinder. In theory Mr. Atkinson was perfectly right as to the expanding charge producing a partial vacuum, or if he might be allowed the expression, its capacity for heat increased by expansion. But, as a matter of fact, that objection vanished in practice, he having gone into that point very carefully. He had taken a full compression charge with a given piston speed working under normal conditions, and he had also taken it when using the expansion or cut-off, and he could not by any means find any appreciable difference in the absorption of heat by the charge from the walls of the cylinder. The loss of piston travel, to which Mr. Atkinson alluded, did not exist in the experimental engine, it being a two-cycle engine. He wished to impress upon the meeting that the engine in question was an experimental engine only. The point which he had expected that Mr. Atkinson would have laid his finger upon was that the very principle of the Lenoir to which he alluded as being bad, viz. cut-off at maximum piston velocity, existed also in this engine. As a matter of fact, that defect theoretically did exist, although by the use of an efficient cut-off its effect was practically nullified. He could not say what its mechanical efficiency really would be, but he knew the indicated efficiency. It was as nearly as possible the same as Mr. Atkinson's, but he was not prepared to state that the brake result would be the same. A 4 horse-power Twin engine was being constructed at his works in order to thoroughly test the system in practice, care being taken to minimise the evil by the use of a very rapid cut-off valve. He had understood Mr. Ridealgh to say that his objection to the Griffin gas engine was that there was a good deal of piston travel. That would hold good in theory with regard to a single-acting engine, but Mr. Ridealgh seemed to have altogether lost sight of the fact that in the double-acting engine the impulses were just double, and that there was one-

third less loss of effective piston travel in the double-acting Griffin engine for a given number of revolutions than in the Otto, because the front end of the cylinder was utilised. At the same time, a great advantage was derived from the fact that as the scavenging charge ejected the products of combustion, the incoming charge was mixed with pure cool air, which assisted instead of retarding the combustion. He presumed that the old idea of stratification was exploded. He thought that any practical man would agree that the desideratum was not to retard the combustion but to make it as rapid as possible. He held that the best way of attaining this result was to supply the incoming charge of gas with as much oxygen as could combine with it, and thus render combustion as rapid and perfect as possible.

Mr. NURSEY asked permission to state, with regard to the difference between the Otto engine and the Purnell engine, that in the Otto there was an ignition valve, while in the Purnell there was none; and that in the Otto engine the admission valve was actuated, and in the Purnell it was automatic.

Mr. GRIFFIN said that he understood that the makers of the Otto held a patent for what they called a timed ignition, by which they admitted the charge into the incandescent tube at a given point of the stroke, but he believed that Mr. Atkinson had no such thing. Mr. Atkinson's ignition was just as valveless as Mr. Purnell's.

Mr. ATKINSON said that he had frequently made experimental engines with self-acting suction valves, but he found that the dancing of the valve prevented the charges from being exactly the same. The only way to get uniformity in the ignition was to lift up the valve definitely and close it definitely.

Mr. GRIFFIN said that he had only to supplement the last statement by saying, that in proportion as the valve was held by a spring, they got the very evil intensified to which he had alluded in connection with the Lenoir. It was necessary to expand the charge until a pressure was obtained equal to the tension of the spring before it would open. The valve must be held down by a spring of considerable tension, which would effectually prevent it from jumping. The overcoming of the tension of the spring involved an amount of negative work which was in proportion to the area of the piston, amounting probably to not less than 6 or 8 lbs. per square inch.

Indicator Diagram.
12 N.H.P. Griffin Gas Engine.

REVS. PER MINUTE	180
INDICATED H.P.	28·7
BRAKE H.P.	23
GAS PER HOUR PER I.H.P.	17·7 cu. ft.
" " " " B.H.P.	22·17 cu. ft.

Fig. 6.

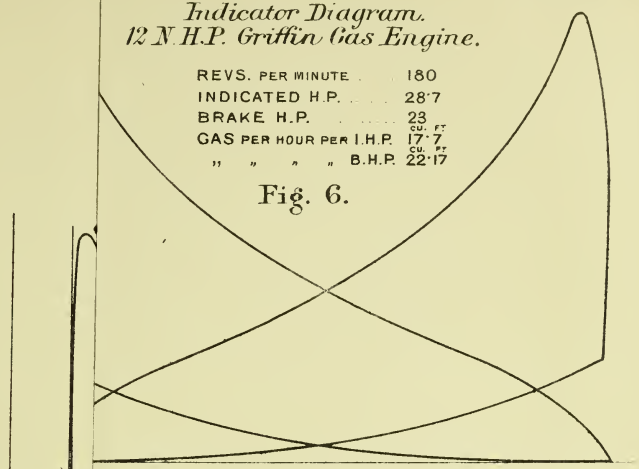
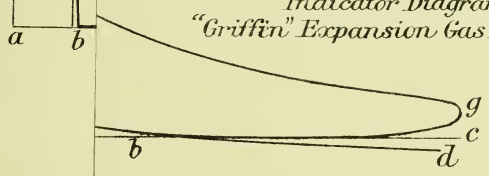


Fig. 9.

Indicator Diagram.
"Griffin" Expansion Gas Engine.



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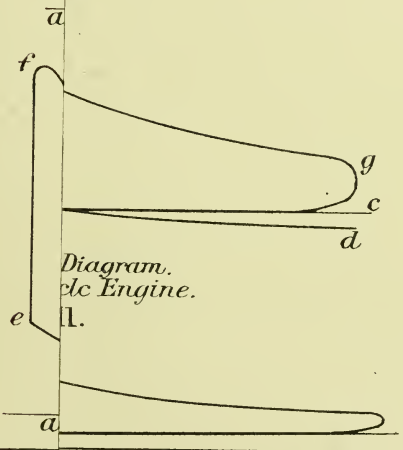

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Fig. 3.

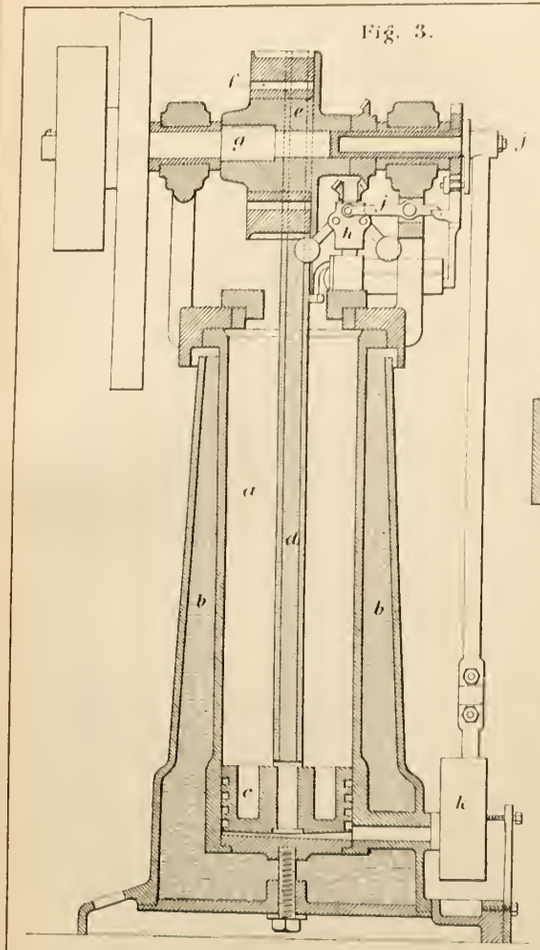


Fig. 7

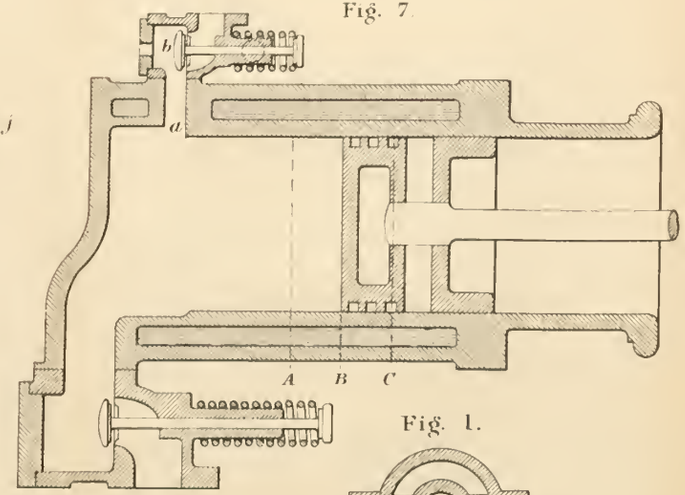
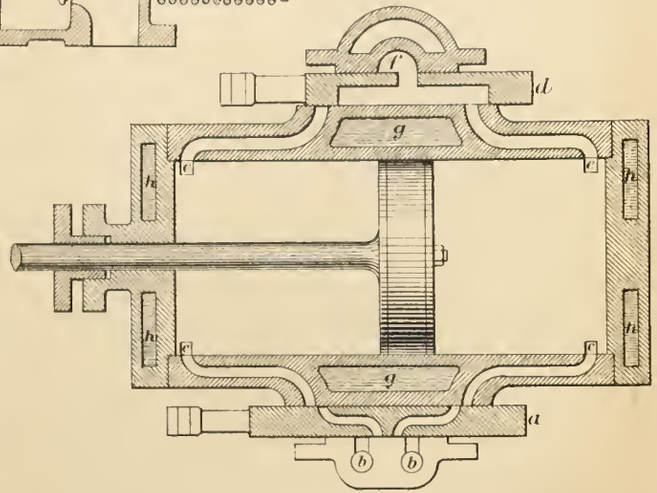
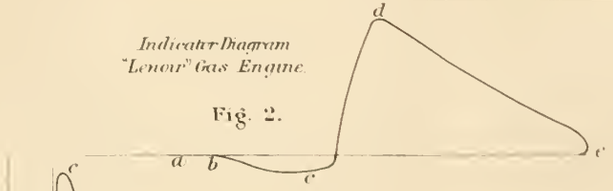


Fig. 1.



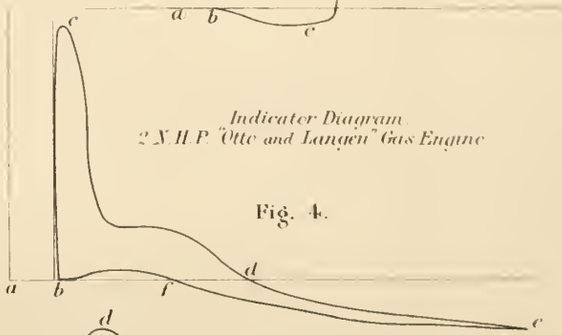
Indicator Diagram
"Lenoir" Gas Engine.

Fig. 2.



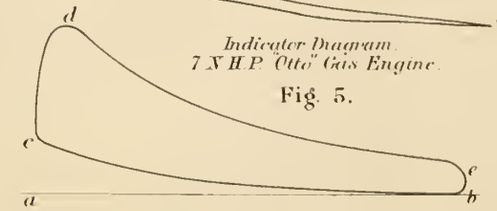
Indicator Diagram
2 N.H.P. "Otto and Langen" Gas Engine

Fig. 4.



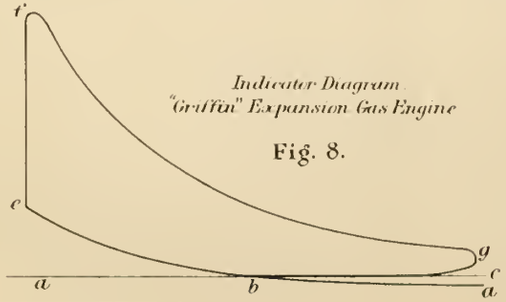
Indicator Diagram
7 N.H.P. "Otto" Gas Engine.

Fig. 5.



Indicator Diagram
"Griffin" Expansion Gas Engine

Fig. 8.



Indicator Diagram
12 N.H.P. Griffin Gas Engine.

REVS PER MINUTE	180
INDICATED H.P.	28·7
BRAKE H.P.	23 "
GAS PER HOUR PER I.H.P.	17·7 "
" " " B.H.P.	22·17

Fig. 6.

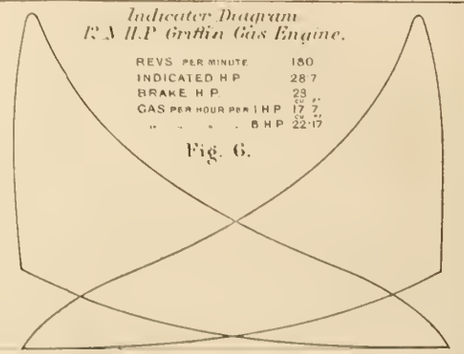
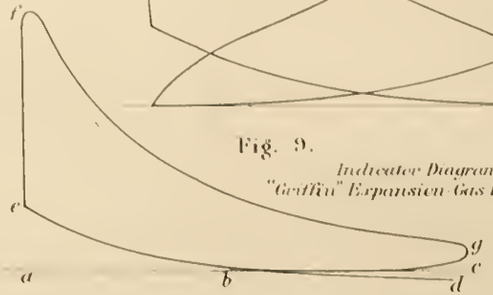


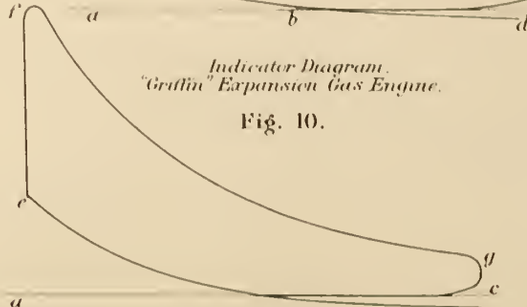
Fig. 9.

Indicator Diagram
"Griffin" Expansion Gas Engine.



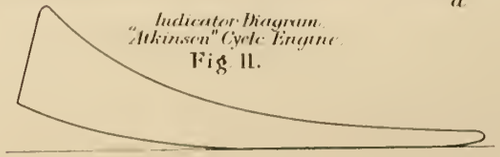
Indicator Diagram
"Griffin" Expansion Gas Engine.

Fig. 10.



Indicator Diagram
"Atkinson" Cycle Engine.

Fig 11.



E & F.N. Spon, London & New York

December 2nd, 1889.

JONATHAN R. BAILLIE, PRESIDENT, IN THE CHAIR.

FOX'S SYSTEM OF SOLID-PRESSED STEEL WAGGON AND CARRIAGE FRAMES.

BY PERRY F. NURSEY, PAST PRESIDENT.

INTRODUCTORY.

WHATEVER the department in mechanical engineering may be into which the introduction of any improvement is attempted, its introduction can only be effected, and it can only become a practical success, provided it fulfils three main conditions. In the first place there must be greater simplicity in construction than existed previously, in the second greater directness of action, and in the third greater economy either in manufacture and maintenance, or in both. If with these can be combined decreased weight and increased strength, with a reduction in the number of parts, we shall have an improvement which is real and substantive, and which, moreover, embodies the elements of practical success. Examples of such improvements are not wanting in mechanical engineering, as the author can testify from personal observation. One of the most recent and withal one of the strident and far-seeing improvements of this type which has lately been brought under his notice, is the system of solid-pressed steel frame-plates for rolling-stock, invented by Mr. Samson Fox.

The production of these frame-plates, however, was not the result of momentary inspiration. It was not pitchforked into existence out of a charge of scrap and pig fortuitously thrown into a converting furnace, run into ingots, hammered, rolled into plates, and swaged out haphazard. It was slowly but surely developed out of an equally important invention of Mr. Fox's, viz. his corrugated boiler flues, which have so largely added to the efficiency and endurance of marine boilers, and which are now used in the boilers of nearly all fast-going steam-

ships. And here, in view of the originality and uniqueness of the invention, the author may perhaps be permitted to say a few words respecting the inventor. Mr. Fox, who is a native of Leeds, was apprenticed to one of the large engineering firms of that town. Being exceptionally gifted, he rose to be in turn foreman, manager, and representative of the firm with whom he served his apprenticeship. His keen perception soon led him to see that there was a good opening for the establishment of works for the production of marine boiler material, and with that promptness which has always characterised him, he set to work to realise the project he had formed. The result was that in 1874 he founded the Leeds Forge Works, was appointed managing director, and there and then commenced the manufacture of his corrugated boiler flue. It was in connection with the flanging of these flues that Mr. Fox gave his attention to hydraulic pressing, and this led him in time to the production of flanged forms in the construction of locomotive side frames and the underframes of rolling stock generally. These are now all turned out complete and perfect at one heat by hydraulic pressure.

The object of the inventor of this process was to produce a plate sufficiently rigid, transversely and longitudinally, without the necessity of introducing angle iron stiffeners, and at the same time to reduce the weight and cost of manufacture. Hitherto, underframes have been built up of pieces of material rivetted together, and constructed partially of iron and wood. Fox's patent flanged frames are composed of a very few parts, and are therefore much more serviceable, and possess much greater endurance than forms built up in sections of differing materials. The system also possesses the recommendation of enabling the various parts to be reproduced in fac-simile an indefinite number of times, with the certainty of perfect interchangeability. Then there is the reduction of the number of parts that go to make up the whole, the attainment of great strength combined with lightness, and a decrease in the cost of maintenance. Steel takes the place of wood and iron, giving only one metal in the construction, which possesses complete homogeneity and uniform strength throughout. Besides this there is the additional advantage that in case of injury by collision the parts are capable of being restored to their original form, and when the waggon has done its work, and is thrown out of service, the material is still valuable as scrap. Steel has superseded wood and iron in shipbuilding and in bridge construction, and the author sees no reason to doubt that in time it will do so in the construction of railway rolling stock generally.

The author has long been familiar with Fox's corrugated flues, but he only became practically acquainted with the pressed frames at the commencement of the present year. Being in Leeds, he visited the Leeds Forge Works, where the method of producing these frames, and also flanged end plates for boilers, was shown to him by Mr. Fox. This is effected by powerful hydraulic presses of large size, which produce and reproduce with perfect accuracy all kinds and shapes of frames made of Siemens steel. The plate to be flanged is operated upon simultaneously over the whole of its surface, and the flanges are formed either inwards or outwards as may be required. Remarkable as the results of this process appeared to be to the author upon that visit, he found when inspecting the Leeds Forge Company's stand at the Paris Exhibition, that further advances had been made. Recognising the importance of the subject, he obtained Mr. Fox's permission to bring the subject before this Society. Availing himself of that permission, and of an invitation to further inspect the process of manufacture, the author again visited the Leeds Forge a fortnight since, when he received every possible courtesy from Mr. Fox and the leading members of his staff. The results of that visit are embodied in the present paper.

The Works.

And first a few words may be said respecting the Leeds Forge Works, which were founded at a comparatively recent date, namely in 1874. They are situate at New Wortley, a suburb of Leeds, and occupy 19 acres of land, of which about 10 acres are now covered with buildings, being an increase of 3 acres in the covered area since the author's first visit in the present year. The works occupy rising ground overlooking the Leeds and Liverpool Canal, which forms a boundary on the north. On the south the Midland and North-Eastern Railway lines are conveniently near, and will shortly be connected with the works by a branch line which is in course of construction. However interesting a description of the works generally would prove, it does not come within the scope of the present paper, although much is being done there, in the way of special production performed in special ways, to justify it. The author, however, will confine his remarks to those portions of the works which it is necessary to describe in brief in connection with that manufacture forming the immediate subject of his paper.

The Steel Works.

It will doubtless have occurred to those present, as it soon did to the author, that the excellent results obtained from the hydraulic press were primarily due to the metal employed, which it is needless to say has to be of the highest quality. This fact was from the first present to Mr. Fox's mind, and he therefore started with the production of his own special steel as a fundamental principle. The steel works will therefore be first described. These comprise twelve Siemens gas producers and three Siemens-Martin open-hearth furnaces. The producers are situate at a lower level than the steel furnaces, so that the producer gas flows upwards. Four out of the twelve producers have closed furnaces, the necessary air being supplied in a fixed quantity through an inlet, the current being induced by means of a jet of steam. The steam jet is so proportioned that the quantity delivered is exactly sufficient to be decomposed without causing a reduction in the temperature on the grate. The gases from all the twelve producers commingle and are conducted through an underground tunnel to the steel melting furnaces. It will be seen that the gaseous fuel with which these furnaces are supplied consists partly of what is known as water gas. It was this arrangement of Mr. Fox's for supplying the Siemens gas producers with a current of air induced by steam, that gave him the idea of using water gas. A water gas plant has been erected at the Leeds Forge, which, as is now generally known, makes alternately producer gas and gas for heating and lighting, and the author first witnessed its successful working about twelve months since. The producer gas is at present utilised only under the boilers for steam raising, the welding of the corrugated boiler flues being performed exclusively by means of the heating gas, a saving of about 10,000*l.* per annum being effected at the works as against the town gas. A portion of the gas is also purified, and with this the works and offices generally are brilliantly illuminated. This reference to water gas is necessary, inasmuch as one of the steel furnaces is now being altered, and will shortly be run on the producer gas made by the water gas plant, the only alteration necessary in the furnace being in connection with the air ports. There are three 15-ton Siemens-Martin steel melting furnaces arranged in line, with the usual casting pit and accessories. The charges consist of the higher class brands of West Cumberland hematite pig and Cumberland hematite ore. The steel ingots have an average size of 3 feet by 2 feet by 16 inches, and an average weight of 30 cwt.

Plate Mill.

From the casting pit the ingots are taken, when cool, to the plate mill, where they are first heated up. The ingot heating furnaces have closed grates, the supply of air being induced by a steam jet in a similar manner to the Siemens gas producers. While a fine heat is maintained in the furnace, the grate bars are kept cool, so cool indeed, that on the grate doors being opened, the author laid hold of the ends of the grate bars without experiencing the slightest inconvenience. From the heating furnaces the ingots are taken to the steam hammer, where they are hammered into slabs. There are four steam hammers, ranging from 5 to 20 tons. From the hammers the slabs are taken direct to the rolls, where they are rolled into plates of varying scantlings, according to requirement. There is a train of 9-foot plate rolls, driven by a pair of condensing engines of 250 horse-power with reversing gear.

The Laboratory.

Before following the plates to the pressing department, it may be as well to notice the precautions that are taken to ensure not only that the steel produced shall be of the high standard necessary, but that the materials used for producing it shall be of the best quality. This duty, of course, devolves upon the chemist's department, and to the laboratory are sent for analysis samples of every kind of raw material that enter the works, including ores, pig-iron, and fuel. Following up this practice, samples of every run are taken, marked, and analysed, and samples of everything made from that run, and at every stage of manufacture are subsequently taken and tested in the same way, the original mark being carried forward on every sample up to that of the finished plate. In the steel, so far as the chemist is concerned, the object is to get 0·1 of carbon.

The Testing Department.

Besides chemical tests, the finished steel is of course submitted to mechanical tests in a well-appointed testing house. In this department is a 50-ton testing machine, and a machine designed and made at the Leeds Forge for making the bending tests. The steel produced must answer to a standard test. This is a tensile strain of from 24 to 26 tons per square inch, with an elongation of from 25–30 per cent. in a marked length

of 10 inches. In the bending trials the steel has to stand the temper test prescribed by the Admiralty, the Board of Trade, and Lloyd's. The author is able to state that the Admiralty inspectors' test books at the Leeds Forge do not contain the record of a solitary rejection for several years past, showing the regularity and exactitude with which the manufacture of the steel is carried on.

It will be seen that the steel to be used in the manufacture of pressed frames is made from the best materials, used in the most careful manner, and that the plates from which the various parts are constructed are of a known regular and uniform quality, having a comparatively low tensile strength with great ductility. To produce this result the best materials only are used, and these are tested before they are given out to the workmen, and at every stage of production. The most perfect plant and machinery are employed, so that the workmen cannot, or ought not—and, as a matter of fact, do not—fail in producing a high-class steel. If any one man at any one stage has a failure, it is at once detected, either by chemical or mechanical means.

The Plate Pressing Department.

From the rolling mill the steel plates pass to the plate pressing department. This is an extensive building, consisting of seven spans 400 feet long and 40 feet wide, and two spans 160 feet long and 40 feet wide, this latter constituting the original plate pressing shop. The plates having been sheared to a certain size and form suited to the direction in which it is desired to form the flanges, are brought to a red heat in the plate furnaces. The plates are run in at the back, and delivered at the front of the furnaces. They are then placed between dies and subjected to a steady hydraulic pressure of 850 lbs. per square inch. The pressure is put on from below, being brought under the lower die by means of four main rams, assisted when necessary by eight auxiliary rams. The presses give the plates their exact finished form, the edges of the flanges alone requiring a slight finish by grinding.

The success attending the pressing operations is due to the fact that the dies have a formation which assists the metal to flow in the direction required, without causing a thinness in the corners, or an excess of metal beyond the required height or depth of the flange, hence the angles of the flanges have in most cases an excess of metal which closely approximates to the

section of a channel or an angle bar. The plate pressing department is not yet complete, but when finished it will contain plant for turning out a complete waggon every ten minutes. This plant is now in course of manufacture and erection. Attached to the press shop is a fitting and erecting shop, where the frames are put together for transport to their various destinations. At the time of the author's visit the presses were busy on side frames for bogies for 20-ton waggons for the Great Indian Peninsula Railway. The plates have 6-feet centres to the wheels, and the flanges vary in depth from 2 to 6 inches. Pressed plates of all sizes and shapes were piled up about the shop ready for delivery, including some sole bars 24 feet long. At the author's request a longitudinal underframe stay of right-angled trough section with square ends was crushed cold under the 20-ton steam hammer. The stay was 5 feet long by 8 inches wide with a 3-inch flange, and was pressed from $\frac{5}{16}$-inch plate. The stay was first laid on its side and doubled close up at the centre, the bottom being pressed outwards and the flanges flattened straight in a line with the pressed-out bottom. The centre part of the trough was, in fact, folded longitudinally like a book cover, all trace of the junction of the flange with the bottom being obliterated by this crucial test. The ends were then put under the hammer and knocked out of shape, but without any damage to the metal. The only fractures were those along the centre of the bottom of the trough where it was doubled over, the hinged part—so to speak—showing a number of fine cracks where the metal had been most severely punished. The corners, where the press treatment may be considered as being most severe, remained good and solid and showed no signs of crack or fracture. This stay-piece was taken haphazard from a pile in the press shop, and its behaviour under the steam hammer testified to the splendid character of the metal from which it was made.

Manufacturing Advantages.

The advantages in manufacture accompanying the pressed plate system are many and obvious. They may be briefly summarised as follows:—(*a*) There is no necessity for a plate straightener. (*b*) Setting out the lines by the foreman is not required. (*c*) Punching out the horn block spaces and various openings is obviated. (*d*) The slotting or shaping of such spaces is unnecessary. (*e*) The drilling for the angle-iron round the top and ends is done away with. (*f*) The entire

labour of the angle-iron smith in straightening, cornering, and squaring is obviated. (*g*) The work of the grinder, the fitter, the driller, or puncher of these angle-irons is rendered unnecessary. (*h*) The steel plate when flanged, though made of thinner material than the steel plate built up, is both lighter and stronger than those in use at present. (*i*) The flanged plates require no straightening nor setting-out after leaving the forge; they may be delivered direct to the erectors.

Examples of Work.

Having followed the pressed plates throughout their production, and having pointed out the advantages attending the special process of manufacture adopted, the author will next proceed to describe—by the aid of diagrams and models—the different styles of waggon frames produced at the Leeds Forge for various railway companies. In order to show clearly the great advance made in Fox's patent system, he will first describe an ordinary timber-built underframe of the Great Northern Railway pattern (Fig. 1). This frame is put together by tenons and sockets, carved out of oak, and there are several pieces each secured together at the ends by angles, stays, and bolts. The number of these pieces is more easily discernible in the oak model exhibited, which is constructed one-eighth size.

A contrast is afforded by the underframe (Fig. 2) made of pressed steel plates for the Great Northern Railway. The parts in this underframe are so disposed as to bring in the existing furnishings, kept in store by the company, wherewith to fit up the draw-gear, buffers, springs, and body. The line of traction is continuous from end to end of the waggon. The total weight of this underframe is not quite half the weight of the timber-built waggon, and it is very much stronger and more durable. The axle guards are put on in separate halves, these being the most likely points to be injured in a collision. By being separate parts, they are more cheaply and easily replaced. The axle guards for these frames are pressed with two corrugations or flutings which serve to impart to a thin $\frac{5}{16}$-inch plate the rigidity of one $\frac{3}{4}$ inch thick. The thickening piece, which forms the wearing surface for the groove in the axle-box, is made separate, and is easily detachable and replaced when worn thin. An alternative method of manufacturing axle guards is to introduce a combination of corrugations or flutings and flanges.

Another type of pressed plate underframe is in use for 16-foot

waggons on the Lancashire and Yorkshire Railway. In this case the horn plates or axle-guards are pressed solid with the sole bars. In the centre of this underframe (in plan) there is an inverted tray. The object of this piece is to ensure and preserve the rectangularity of the underframe in the same way as the bottom of a box serves to keep the sides square.

Going a step further in construction, a complete waggon formed of pressed steel plates may be described. The underframe is similar to that last mentioned, and upon it is mounted a body composed of pressed flanged steel plates. The entire body is formed of twelve parts only, of the simplest form of construction. The flanges securing the end plates are fish-backed to give rigidity to withstand jerk and recoil when in service. The floor is of wood, as being more cheaply replaced in case of injury to the waggon by being used for the conveyance of pig iron, iron ore, or similar materials.

A description may next be given of the bogie system as applied to a 32-foot 20-ton goods or timber waggon, mounted on two bogies. This class of waggon is very much in use in Belgium, where it has hitherto been built by a combination of channel iron, angle iron, king-posts and truss-rods. In the new type the whole of the underframe is built of pressed flanged plates. The sole bars are rivetted together where they join in the centre vertically, and the strength of this joint is further increased by fixing two broad transoms, one at the top edge and the other at the bottom. The bogies or trucks at each end are also made on Fox's system and are fitted with four small transoms or cross bars. Behind the drawhook is a dished girder which distributes the force of traction more evenly throughout the entire headstock.

Another type of bogie truck has been designed to suit the narrow gauge on the Indian State Railway. The side frames or sole bars are made sufficiently long and are afterwards bent over at right angles, thus forming the end transoms. By making these sole bars longer or shorter, any width of gauge can be accommodated. The centre cross beam is made in one piece, and is secured to the cross bars by rivets. The rubbing plates at each end serve to distribute the weight of the underframe upon the wheels.

American practice in this direction is illustrated by a four-wheeled bogie truck, as made for one of the railways centring in Chicago. This form of truck may be made with either a rigid or a swinging bolster. The axle boxes are fixed in a recess prepared for them, and the elasticity of the truck is dependent upon a nest of four or more springs placed at each end of the

rigid and top bolster. The bogie centre plate is removable, and is also made under Mr. Fox's patent.

Turning to another example of construction, a description may be given of an underframe designed for carriages in use on the Manilla Railway. The point of difference between this underframe and that of the 16-foot waggons on the Lancashire and Yorkshire Railway lies in the application of pressed flanged diagonals in the same position as formerly occupied in the timber constructed underframe. The headstocks, or buffer beams, are deeply flanged over, and, together with the central tray, ensure continual rectangularity of the whole structure. In this case the old-fashioned W axle guard is employed.

A crucial test was made with a pair of pressed steel bogie trucks in November 1888, as shown in Fig. 3. Each bogie was 6 feet long between centres, and weighed 812 lbs. They were placed 12 feet apart, and loaded with 130,186 lbs. of pig-iron distributed over the two bogies as shown. The result was that there was no deflection whatever, as can be seen by the normal position of the indicating instrument under the centre of each frame, the engraving having been made from a photograph in the author's possession.

Some of the first pressed frame plates turned out at the Leeds Forge were for bogie frames for the Pennsylvania Railway, and the demand for the plates in the United States became so great that works were at once established at Joliet, Illinois, and are now successfully running. It may be interesting here to enumerate the railways on which pressed frame plates are either already in use, or for which orders are in course of execution. They are, the Great Northern, the Great Western, the London and South-Western, the Lancashire and Yorkshire, the North-Eastern, the Great Indian Peninsula, the Indian State, the South Indian, the Bengal Nagpur, the Belgian State, the Grand Central of Belgium, the Belgian Suburban, the Central Argentine, the Manilla, the San Yo (Japan), and the Imperial Railways of Japan. Pressed plates are also in use by several of the leading carriage and waggon building companies. The rapidity with which the merits of Fox's system have been recognised will be realised when it is stated that the output only commenced about a year and a half ago.

Practical Considerations.

The author will now proceed to notice the practical and commercial considerations bearing upon the subject of his paper. One of the most important desiderata in connection with rolling stock is lightness, and Fox's system goes direct to this point, inasmuch as it materially reduces the dead weight hauled. Whether the frame be built of bars and angle iron, or constructed of oak, the weight of the waggon will be about 4 tons 14 cwt., and this will represent a waggon capable of carrying a load of 8 tons. Now, 8 tons is regarded by the railway companies as constituting a standard load. As a matter of fact the companies do not always get this load per waggon, and they have, of course, to start their goods trains with such loads as they have been able to procure. A careful consideration of this point leads to the conclusion that the average load carried per waggon is about 34 cwt. It follows, therefore, that an ordinary waggon constructed to carry 8 tons, and weighing 4 tons 14 cwt., is doing work that could be as efficiently done by a much lighter vehicle. By the pressed plate system, the weight of the frame is at once reduced by 1 ton, that is to say, instead of the weight of the waggon being 4 tons 14 cwt., it will only be 3 tons 14 cwt. We therefore have 20 per cent. taken off the dead load at once, the load consequently becoming worth one-fifth more. We thus obtain as an important result a marked increase of revenue-earning power.

So much for the question of dead weight hauled. But there is a further and most important consideration, and that is with regard to the capital account. If the bulk of a company's rolling stock be constructed of oak, in the course of a few years such an allowance must be made for depreciation that the rolling stock will appear on the books practically as "chips." Allowing perhaps for the removal from the wood frame of one or two of the principal parts, the remainder, constituting the bulk of the frame, is burned for the sake of the bolts. It does not pay to remove these by ordinary manual labour, so for their cheap recovery resort is had to fire. The result, however, is widely different in the case of steel frames. It is a standard rule that scrap steel which has been at work is always worth as much in the market as pig-iron, because there is less waste in remelting old steel, and there is no loss due to having to free it from carbon. Under these circumstances the material of pressed steel frames can always be shown among assets as of the value of pig-iron at the market price of the day. The depreciation

of and injuries received by timber-built waggons in active service not only entails a much larger stock of vehicles, but also necessitates the erection of large repairing sheds, with the requisite machinery and labour for executing repairs. The author considers that the adoption of the pressed plate system would enable railway companies to work their traffic with a smaller number of waggons, and that their stock would be more continuously in service and less frequently in hospital. Such a condition of things would undoubtedly contribute to the dividend-earning power of the capital employed.

Next, a few words respecting the facilities for interchangeability and duplication possessed by the pressed frame system. Where a railway company decides upon a standard design, it naturally follows that, suitable dies having been made for these standards, each part can be reproduced an indefinite number of times with perfect exactitude. Stocks of the various parts may, therefore, be laid in, and replacements can be effected without any delay. This principle of duplication is one of the most valuable features of Fox's system.

Another important feature for notice is the elasticity which a waggon so constructed possesses. A frame having a high degree of elasticity cannot possibly destroy itself so quickly as a rigid frame. We cannot have action without reaction, and when a shock is imparted to a pressed frame waggon, say by a sudden stoppage, the blow is distributed uniformly throughout the frame, and, owing to the high elasticity of the whole, each part is well able to take care of itself. In a rigid frame, however, such a shock would naturally cause far greater deterioration than in the more elastic frame. If rolling stock be constructed of an elastic material, which after receiving a shock, is capable of giving it back, little or no harm can be done to the stock under the ordinary conditions of working.

Another point of great advantage is that in the new system the number of parts is very materially reduced. In a waggon frame they are brought down to about fourteen parts, as against about forty-seven in the ordinary method of construction.

Cost.

A natural inquiry here will doubtless be with many—At what cost may we obtain all these advantages? The answer is simple and satisfactory, and has, moreover, been formulated out of practical experience in manufacture. Briefly, it is this: Standard designs, as prepared at the Leeds Forge Works, cost

about the same as those of the present ordinary construction. Where intricacy of design comes in as a requirement, the cost is higher than that of the composite frame. It should, however, be borne in mind that this comparison of cost assumes that the order to be executed is for a number of frames of the same pattern—say a hundred. Obviously one wood and iron frame could be built for less money than the tools could be fixed for making one frame on Fox's system. Generally speaking, the materials of the Fox frame cost more than those of the composite frame, but the parts in the former being much fewer in number and interchangeable, there is a very great saving in the cost of erection. It will thus be seen that comparisons are favourable to the pressed plate frame *qua* frame, and are entirely irrespective of its superior practical advantages in use. If we combine with these the longer life of the pressed plate frame—which is relatively about twenty years, as against ten years in frames of the ordinary type—we have advantages which far outweigh any serious considerations respecting higher first cost, but which otherwise might very properly be entertained.

Conclusion.

The author has now placed Fox's system and its advantages before the members. If he has done so somewhat imperfectly, the system itself will make up for his shortcomings, as, to an engineer, it fully tells its own plain story. He believes, however, that he has succeeded in showing that the system embodies all the attributes set forth at the commencement of the paper, and that it therefore constitutes a practical and a practicable mechanical improvement. It marks very definitively an important and far-reaching epoch in railway rolling stock construction.

Discussion.

Mr. G. A. Goodwin said they were all very much obliged to the author for the excellent manner in which he had brought this subject before them. It was one of particular interest, because so few engineers had opportunities of getting the experience of hydraulic presswork, the plant being so very expensive. The author had said that 850 lbs. per square inch was the steady pressure which the plates were subjected to. Probably by that was meant the pressure of the accumulators. It was rather an

important point to know whether it was this or the pressure per square inch on the plates operated on, because he (Mr. Goodwin) was not aware of any particular law that governed the pressure to be put on a plate to effect a given purpose. If any such law could be obtained, it would be very valuable. He did not think the analysis with reference to the amount of carbon in the steel was sufficient in itself to deduce therefrom what its characteristics would be; in fact, the analysis of carbon alone was not sufficient to determine what the strength and reliability of the steel would be. The tests alluded to by the author were, it was to be assumed, that the steel was heated to cherry red, dipped in water at 82° Fahr., and then bent so that the ends were parallel, the inner surface of the plate having a radius of one and a half times its thickness. He should like to ask if the plates were annealed after they were pressed, particularly in the case of thin plates, and were the plates cut into approximately the required shape before the pressing operation? In the manufacture of frames of locomotives and similar constructions there was, of course, a large proportion of plates to be cut away; but as Mr. Fox made his own steel, probably he could make it up again with only a moderate amount of loss.

One great advantage derived from the use of steel frames for waggons and carriages had not been touched upon, viz. that they did not splinter in case of collision. He would like to know whether experience had shown as to how long steel frames and bodies would be in use before they required repainting? Steel rusted very much when exposed to the ordinary changes of the weather if not attended to. Another great advantage of this construction of carriages, &c., was their lightness, inasmuch as it necessitated less tractive force and gave less wear on the journals and bearings, which meant increased economy. He did not quite catch the relative costs of waggons having the same given capacity. There could be no doubt that when steel frame waggons were sent abroad they would be cheaper than the ordinary type, owing to the greater facility in putting them together, and less freight expenses. In the models of some bogie frames exhibited he pointed out that they appeared somewhat weak, and required some diagonal ties. The test load the actual frames had been put to, as illustrated in the photograph on the wall, to his mind did not prove they were stiff enough, as there was a great difference between the strains induced by a simple static load and those arising when running on a road subject to all the various shocks, jars, and lateral strains, especially when going round sharp curves.

Mr. JOHN BARBER, of the Leeds Forge Works, replying to the questions raised, said that the test was distinctly the same boiler test that was used by the Admiralty, the Board of Trade, and Lloyd's. At the works only one quality of plate was made. The pressure was 850 lbs. per square inch in the accumulators, and that operated upon four hydraulic cylinders, each of 3 feet in diameter, and gave 4500 tons upon the object. Nothing as yet had been done under $\frac{1}{4}$ inch. The press went down home and back again directly. It would hardly do were it otherwise, as the object pressed might contract too rapidly upon the die. They had made fronts for boilers up to 16 feet in diameter and $1\frac{1}{8}$ inch thick, with three and four furnace holes, and flanged all round the edge, at the same time as the furnace holes; also tender plates $\frac{7}{8}$ inch thick and 21 feet long. As to the analysis of the steel, he was not a chemist, and even if he were, he did not think he would be justified in mentioning what the analysis of the Leeds Forge steel was. The specimens of the work done and the mutilated sample produced was sufficient evidence as to its quality. It was not necessary to anneal the plates, because they were all heated to one uniform heat and allowed to cool equally and gradually. With regard to durability it was impossible to give an opinion yet. They must wait half a century before speaking about that. He did not think they would be more liable to want painting than other work. From what he knew of waggons in Belgium built of iron and steel, they did not require very much more attention in this respect than other stock. A great number of waggons, and carriages also, on the Great Western Railway here, had been running for many years with sheet-iron panels fastened on to wood frames. Nearly all the third class carriages on the South Wales portion of the Great Western used to have sheet-iron faces on timber structures. The solid pressed frames in the model produced were not stiffened at all. The model would be very different with its wheels, axles, and boxes on. They were fixed boxes in the American specimen, there being no allowance for vertical sliding.

The following communication, addressed to the Secretary of the Society, has been received from Mr. STROUDLEY, Locomotive Superintendent of the London, Brighton, and South Coast Railway:—". . . I said, Carriage bogie frames were being made by the Leeds Forge Company for the London, Brighton, and South Coast Railway, which were of a somewhat different design to those before us, the flanging at the top and bottom of the frame being as much as 7 inches deep, this causing great difficulty in flanging, the drawing of the metal on inner side of

horn block and the taking up on outer side being very great. This required a considerable amount of care, to prevent the flange drawing apart on inner side, but the Leeds Forge Company have turned them out a creditable and satisfactory piece of work. The frames were made of $\frac{3}{8}$-inch steel plate. We have also had carriage axle guards made by the same firm, of $\frac{5}{16}$-inch steel plate, and flanged to $1\frac{1}{2}$ inch deep, which have also proved themselves very satisfactory."

Mr. J. H. CUNNINGHAM said there could be no doubt that the frames described by the author possessed all the advantages that he had claimed for them. One of these was that they could be used in the existing rolling stock, and therefore the railway companies might adopt them without making any serious changes in their methods of handling the goods traffic. It appeared to him (Mr. Cunningham) that the frame for the Manilla Railway waggon, which was stiffened by diagonal braces, was in this respect much superior to the Lancashire and Yorkshire one, which consisted of rectangles without diagonal bracing of any kind. He had recently been looking into the cost of carrying the goods traffic, and the facts which came before him pointed to the conclusion that, in order to secure the utmost economy, it would be necessary to discard the 4-wheeled 18-feet waggon which carried 9 or 10 tons, and substitute for it a 34-feet waggon, mounted on bogies, which would carry 30 or 40 tons. But a change of that kind would almost amount to a revolution in rolling-stock, and he was afraid that it was not likely to be brought about at once. These long waggons were very economical for moving goods, and the only objection to them which he was aware of was their excessive wheel load. The load on each wheel was liable to be so great as to cause a crushing stress which would strain the metal in the rails beyond its limit of elasticity, and so cause excessive wear in them. But if this difficulty was faced, it could be overcome. He hoped that a great many of Mr. Fox's frames would be used, because he thought their introduction would be a step in the right direction, and that it might lead to the adoption of long bogie waggons.

Mr. W. PANTER said that he had taken very great interest in these bogies from the first time he saw the models. He brought them to the notice of the directors of the South-Western Railway Company, because he thought there was much in them worthy of consideration. Some had been running for twelve months, and had proved highly satisfactory. There was a very great saving in weight as well as in other points. A waggon, built on the same principle as the model, had been in regular

work for about fifteen months with very satisfactory results. His directors had ordered 25 sets more of the bogie carriages, and they would probably be running in the course of three or four months.

Mr. F. Klein said that the application of the principle was almost unlimited. It could be adapted to nearly everything required in rolling-stock, and in fact, at the present moment there were inquiries right and left from engineers in London and elsewhere for the pressed frames. Thousands of pieces could be turned out alike, and thus all the labour of shaping and cutting might be saved. The number of parts required for a framing, and also the rivets and rivet holes, were reduced to about one-half of those that were ordinarily used in the construction of an iron or steel underframe. The whole thing was formed solid, and that surely must be a great advantage. The things could be sent to foreign parts, without requiring skilled labour there for erection. Every part was first of all stamped in the die to a certain shape; it was then passed on to the machine, by which all the necessary holes were drilled. All that was afterwards required was to rivet them together. There was no difficulty in designing them. They could be shaped to suit any existing railway waggon, and a great deal would be saved in the dead load. By the same motive power perhaps 50 per cent. more paying weight could be carried.

Mr. Walter Brierley said that although he had not had the advantage of hearing the whole of the paper, the diagrams and models were sufficient to allow of the question being thoroughly understood, and on the face of it the invention seemed to be one of utility and value. Everybody could realise the difficulty of getting foreign workmen to understand what was required of them, but here the parts were all ready for simply rivetting together. As to the question of durability of paint when applied to metallic waggons, he (Mr. Brierley) did not think there was much to give rise to argument, as there were in this country a not inconsiderable number of trucks having sheet metal ends and sides, and such seemed to "weather," he thought, as well as painted trucks constructed of wood.

Mr. Nursey, in reply, said that the questions asked by Mr. Goodwin had been answered by Mr. Barber, so that he had not to deal with them. With regard to the frame to which exception had been taken by Mr. Cunningham, it was made to the design of the engineer of the Lancashire and Yorkshire Railway, and all that the Leeds Forge Company had to do was to work that design. He (the author) quite agreed with Mr. Cunningham that the frame for the waggons for the Manilla

Railway was superior in design to that for the Lancashire and Yorkshire Railway. Mr. Panter bore very valuable testimony to the importance and practical nature of the invention when he stated that 25 more sets of frames had been ordered by the London and South-Western Railway Company. With regard to cost, that could not be so much an object in view of the constructive value of the steel when made up into a frame. The system gave considerably increased life to the rolling-stock, and a comparative degree of safety in cases of collision. The cost would of course vary according to the simplicity or complexity of the design, and also according to the number of frames produced from the same patterns.

Fig. 1.

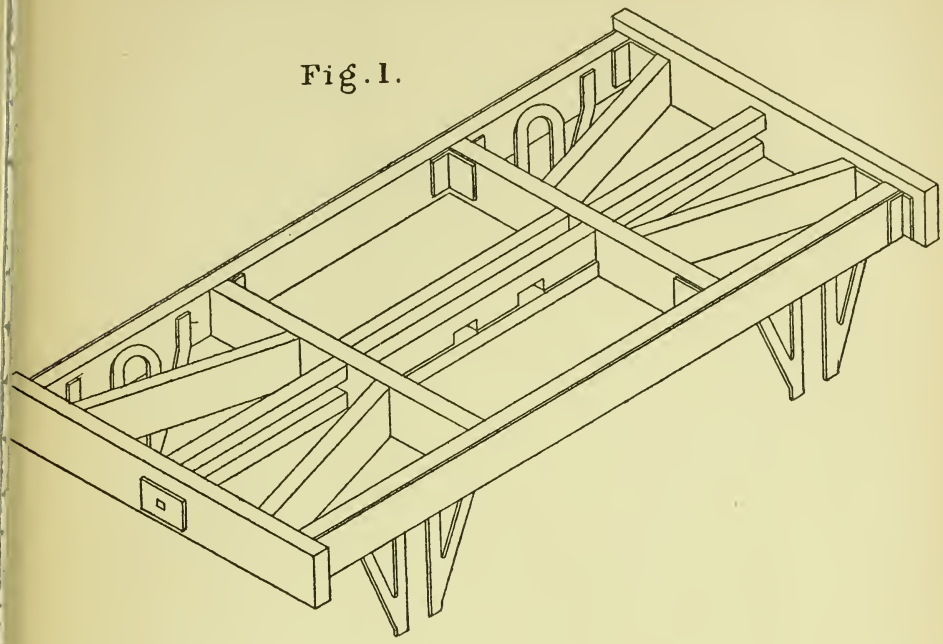


Fig. 2.

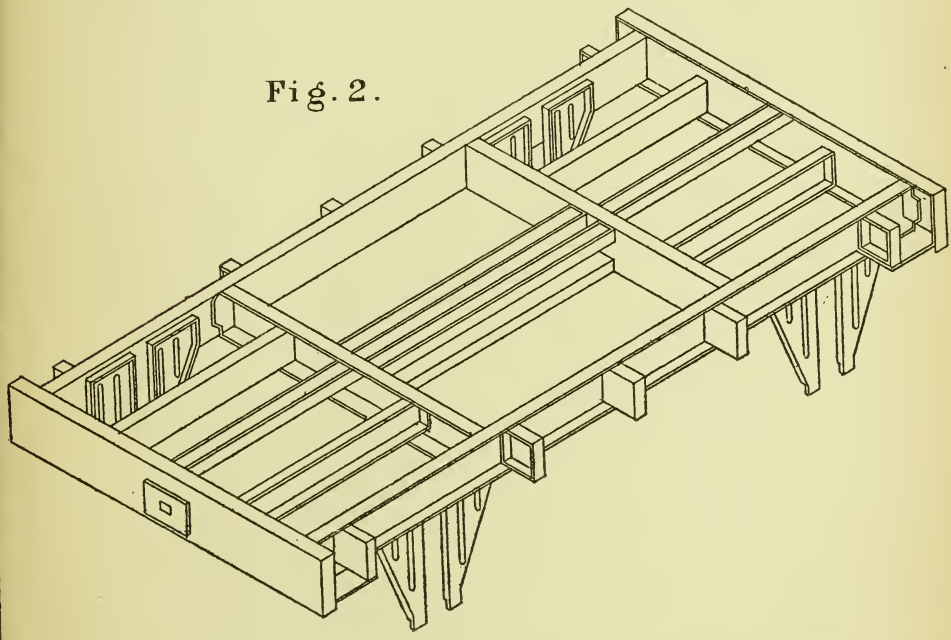
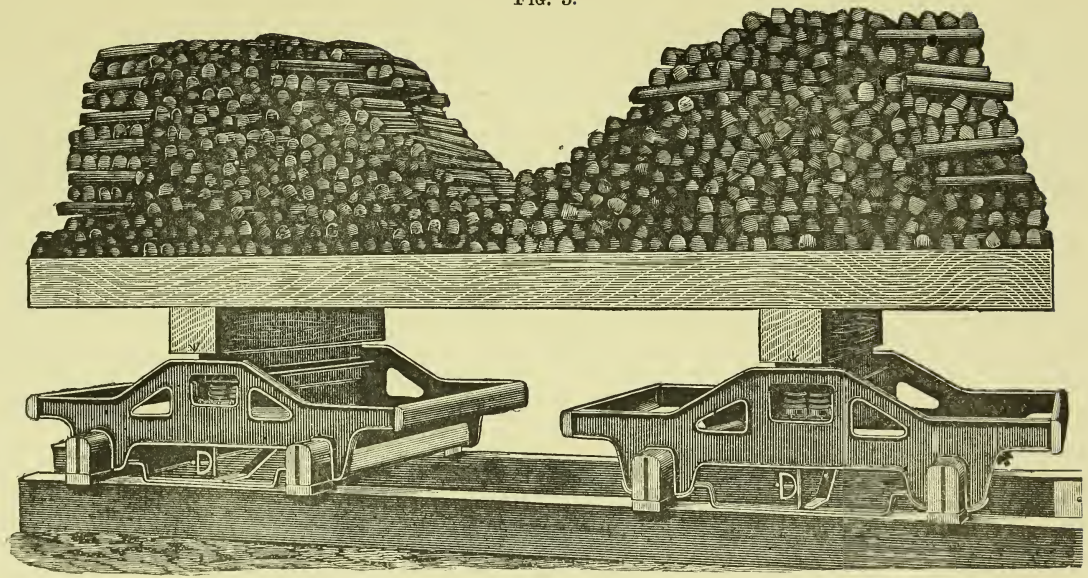


Fig. 3.



Obituary.

George Campbell (*Member*) died 2nd July, at the age of 53. He served his apprenticeship with Messrs. E. B. Wilson and Co., of Leeds, and was engaged for them in delivering engines of their make to the Madrid and Alicante Railway in 1858. He was then engaged by Messrs. Manning and Wardle, of Leeds, and remaining with them for some fourteen years, attained to a position of considerable trust. He left there to become a partner of his brother, Mr. James Campbell, of the Hunslet Engine Company, with whom he remained up to the time of his death. His principal practice lay in designing locomotives required for special purposes.

Robert Riches Lindsley (*Foreign Member*), died in Johannesburg, South Africa, June 19th. He was a son of Mr. George Lindsley, Locomotive Superintendent of the Great Western Railway at Swindon, and was born at Worcester in 1861.

He served his apprenticeship at the Great Western Railway Locomotive Works at Swindon, and afterwards proceeded to the Cape, having obtained an appointment on the Cape Government Railways.

After some years in that service, he went to the Transvaal Gold Fields, and at the time of his death, from typhoid fever, was a member of the firm of W. L. Doveton and Co., mining engineers.

Harry Robert Newton, A.R.I.B.A. (*Associate*), who died in London on the 14th November, at the age of 61, was the son Sir William Newton, the miniature painter, and was a collateral descendant of Sir Isaac Newton. He was an architect and surveyor engaged in sanitary questions, and had a large private country practice connected with architecture.

John Percy, M.D., F.R.S., F.G.S. (*Honorary Member*), died June 19th, at his residence in Bayswater, at the age of 72 years.

He was the son of a Nottingham solicitor, and took his degree of M.D. at the University of Edinburgh, at the age of 21, afterwards studying in the medical schools of Paris. Later, he established a practice in Birmingham, and was appointed physician to the Queen's Hospital.

It was his residence in Birmingham that induced him first to take that direct interest in the chemical principles affecting metallurgical questions, to which he afterwards entirely devoted

himself so effectively, and with which his name will always be associated.

In 1851, on the establishment of the Government School of Mines, he was selected for the appointment of Lecturer on Metallurgy, and held that post until his retirement in 1879. In 1861 the first volume of his celebrated treatise on metallurgy was published, and dealt principally with the subjects of fuel, copper, and zinc. In 1864 it was followed by the issue of a treatise upon iron and steel, and later on, lead, silver, and gold were the subjects dealt with.

In 1863–8 he held the Gurney Lectureship on Geology, and delivered a series of lectures on 'Chemical Geology.' The Bessemer medal was awarded to him in 1877 by the Iron and Steel Institute, of which he held the post of president from 1885 to 1887, and in the latter year also he was awarded the Howard Prize of the Institution of Civil Engineers. He also held the appointment of Superintendent of Ventilation in the Houses of Parliament.

His investigations in the science of metallurgy were, by his lucid writings, placed at the disposition of the world, and in his public character as a lecturer and teacher he ever commanded popularity and respect.

George Spencer (*Member*) died at Montreux, in Switzerland, on the 5th June, at the age of 79.

He was born at Brighton in 1810, and after attending the engineering classes at the Birkbeck Institute, became an assistant in the drawing office of Mr. George Dempsey, and was largely engaged in surveying in various parts of the country during the railway fever period, viz. 1845 to 1848. He was later engaged by Messrs. Fox and Henderson in assisting in the design and erection of bridges, roofs, &c. He also took part in the construction of the Crystal Palace, and in the design and construction of the Bricklayers' Arms Station for the South-Eastern Railway.

About thirty years ago he founded the business of Messrs. George Spencer and Co., principally engaged in supplying india-rubber springs for railway rolling-stock, and introduced several improvements in their manufacture.

Robert Paulson Spice, M. Inst. C.E., M.I.M.E. (*Past President*), died in London on the 14th May, at the age of 75.

He was born in Norwich, 1st January, 1814, and notwithstanding the disadvantages of a limited book education (compensated for, however, by a sound mechanical education), was enabled, through being endowed with an unusual strength of

character and clearness of mind, compelling success, to take his stand in the foremost rank as an adviser of great reliability upon all questions relating to the construction of works and supply of gas.

His connection with gas engineering was commenced by the construction, in 1843, of the works for lighting the town of Fakenham, and after leaving that place, he settled in Richmond, Surrey. In 1860 he opened offices in London, and subsequently became lessee of various gas undertakings in the suburbs of the metropolis.

He also constructed gas works at Hoddesdon (being intimately connected with the foundation of that company in 1847), at Abingdon, Boston, Hartley Wintney, Great Yarmouth, Tattershall, Tunbridge Wells, &c.

His engineering work extended over a period of half a century, and his consequent experience made him highly valuable as a technical witness and umpire in all questions bearing upon gas supply and manufacture.

He was also interested in the experiments for the production of water gas, and read a paper on the subject at a meeting of the British Association of Gas Managers in 1875. He had also, up to within a short time before his death, been fully in touch with all questions bearing upon improvements in lighting.

William Stroudley, M. Inst. C.E. (*Member*), Locomotive Superintendent of the London, Brighton, and South Coast Railway, died 20th December, having been born in Oxford in 1833. His success in life was entirely due to his own exertions and the mechanical genius with which he was endowed. Commencing work as a lad in a paper mill in his native place, he, in 1847, was apprenticed to Mr. John Inshaw, of Birmingham, and after leaving there, in 1854 had worked his way up to the post of foreman in charge of passenger engines on the Peterborough division of the Great Northern Railway. In 1861 he obtained the appointment of manager of the Cowlairs Works of the Edinburgh and Glasgow Railway Company, and four years later became the Locomotive and Carriage Superintendent of the Highland Railway. He continued there until his appointment in 1870 to the post which he held up to the time of his death, which occurred in Paris, after a brief illness, originating in a cold caught while travelling to be present at a trial of his express engine (the Wilfrid Blunt, which gained a gold medal at the recent Paris Exhibition) on the Paris, Lyons, and Mediterranean Railway.

Mr. Stroudley was remarkable for his independence of established usage in dealing with questions associated with mechanical

engineering, and was unwilling to adopt any conventional form of construction until he was satisfied that it was the best.

In addition to his province of locomotive engineer, he was also marine superintendent engineer, and was responsible for the design and construction of the Company's Channel boats, running between Newhaven and Dieppe. From a series of experiments made by him upon various models of hulls for ascertaining the requisite data regarding displacement, stability, &c., he was enabled to design and construct a type of vessel which is now generally accepted as the correct one for channel service.

In locomotive construction he early adopted the idea of interchangeability of parts, making the engines of each class identical in all respects, and also so as to allow of interchangeability of many of their parts with those of other classes of engines, and by this method he was enabled to institute a workshop system exceedingly simple in character.

It was his endeavour to imbue the drivers and others in charge with the same interest and pride in their work as he himself possessed, and this was fostered by his having the name of the driver and fireman painted on each engine, together with the number of miles run since the previous overhauling; the result being that the extra amount of care each engine thereby received was found to more than compensate for the loss due to the fact of the engine being only worked by one and the same set of men.

Mr. Stroudley will be remembered as an engineer in the full sense of the word, and in addition, by those intimate with him, as a charmingly genial, simple-minded man, ever ready to place at the disposal of his friends the results of his great experience and vast store of information.

SOCIETY OF ENGINEERS.

INDEX TO TRANSACTIONS,

1861 to 1889.

AUTHORS.

Author.	Subject of Paper.	Transactions. Year.	Page.
A.			
Abel, C. D.	The Patent Laws	1865	25
Adams, J. H.	President's Address	1875	1
Adams, T.	The Friction of the Slide-valve, and its Appendages.	1866	6
Adams, W.	President's Address	1870	1
Alford, C. J.	The Mineralogy of the Island of Sardinia.	1879	93
„ „	Appendix to Above: Laws relating to Mining.	1879	106
„ „	Engineering Notes on Cyprus	1880	131
Alford, R. F.	The Fell Engines on the Rimutakai Incline, New Zealand.	1882	121
Anderson, Chris. ..	The Feasibility and Construction of Deep-sea Lighthouses.	1883	45
André, G. G.	The Ventilation of Coal Mines	1874	23
„ „	The Application of Electricity to the Ignition of Blasting Charges.	1878	123
Andrews, T.	The Strength of Wrought-iron Railway Axles.	1879	143
Atkinson, J.	Apparatus for Utilising the Waste Heat of Exhaust Steam.	1878	167
Ault, E.	The Shone Hydro-Pneumatic Sewerage System.	1887	68
B.			
Baldwin, T.	Single and Double Rivetted Joints ..	1866	150
„ „	Experimental Researches into the Nature and Action of Safety Valves for Steam Boilers, &c.	1867	23
Baillie, J. R.	President's Address	1889	1
Bamber, H. K.	Water, and its Effects on Steam Boilers.	1867	65
Bancroft, R. M. ..	Renewal of Roof over Departure Platform at King's Cross Terminus, G.N.R.	1887	125
Barker, C. M.	The Prevention of Leakage in Gas and Water Mains.	1869	79
Barker, E. D.	Hydraulic Continuous and Automatic Brakes.	1879	75
Barker, Capt. W. B.	International System of Marine Course Signalling.	1884	47
Barnett, S., junr. ..	The Value of Exhibitions as Aids to Engineering Progress.	1883	75
Bartholomew, E. G.	Electric Telegraphy, irrespective of Telegraphic Apparatus.	1869	55
„ „	Electric Telegraph Instruments ..	1872	53
„ „	Electrical Batteries	1872	77

Author.	Subject of Paper.	Transactions. Year.	Page.
Beaumont, W. W. ..	Modern Steel as a Structural Material	1880	109
„ „ ..	High Pressure Steam and Steam-engine Efficiency.	1888	221
Behr, F. B.	The Lartigue Single-rail Railway ..	1886	163
Bellasis, E. S.	The Roorkee Hydraulic Experiments	1886	41
Bernays, J.	President's Address	1880	1
„ „	The New Pits and Hauling Machinery for the San Domingos Mines in Portugal.	1879	29
Biggs, C. H. W., and Beaumont, W. W.	Notes on Electric Light Engineering	1882	23
Björling, P. B.	Direct-acting Pumping Engines ..	1877	79
Blackbourn, J.	The Action of Marine Worms, and Remedies applied in the Harbour of San Francisco.	1874	111
Bower, G.	The Preservation and Ornamentation of Iron and Steel Surfaces.	1883	59
Bryant, F. W.	President's Address	1869	1
Buckham, T.	The Drainage and Water Supply to the Town of Fareham.	1869	41
C.			
Cargill, T.	President's Address	1877	1
„ „	Railway Bridge at the Place de l'Europe, Paris.	1866	191
„ „	Floating Breakwaters	1871	146
Carrington, W. T. ..	President's Address	1865	1
Carter, J. H.	Roller-milling Machinery	1883	125
Church, Jabez	President's Address	1872	1
„ „	President's Address	1873	1
Church, Jabez, junr. ..	President's Address	1882	1
„ „	President's Address	1883	1
Colam, W. N.	Cable Tramways	1885	69
Colburn, Zerah ..	President's Address	1866	1
„ „	The Relation between the Safe Load and Ultimate Strength of Iron.	1863	35
„ „	Certain Methods of Treating Cast Iron in the Foundry.	1865	77
Conradi, H.	Stone-sawing Machinery	1876	135
Copland, H. S.	Modern Roadway Construction	1878	61
Cox, S. H.	Recent Improvements in Tin-dressing Machinery.	1874	11
Cramp, C. C.	Tramway Rolling-stock and Steam in connection therewith.	1874	119
Crimp, W. S.	The Wimbledon Main Drainage and Sewage Disposal Works.	1888	73
Crompton, E. S.	The Economics of Railway Maintenance	1870	101
Cullen, Dr. E.	The Surveys of Proposed Lines for a Ship Canal between the Atlantic and Pacific Oceans.	1868	15
„ „	The Panama Railroad	1868	39
„ „	The Isthmus of Darien and the Ship Canal.	1868	52
Cunningham, J. H. ..	Pin-connected *v.* Rivetted Bridges ..	1889	135

Author.	Subject of Paper.	Transactions. Year.	Page.
D.			
Danvers, F. C.	Engineering in India	1868	137
Davey, H.	Pumping Engines for Town Water-supply.	1867	88
„ „	Milford Haven and its New Pier Work.	1872	89
„ „	Recent Improvements in Pumping Engines for Mines.	1873	182
„ „	The Underground Pumping Machinery at the Erin Colliery, Westphalia.	1876	119
Day, St. J. V.	Recent Arrangements of Continuous Brakes.	1875	87
E.			
Edwards, E.	Utilisation of Waste Mineral Substances.	1861	82
Engert, A. C.	The Prevention of Smoke	1881	101
„ „	Defects of Steam Boilers and their Remedy.	1884	25
„ „	The Blow-pipe Flame Furnace	1884	185
F.			
Faija, H.	Portland Cement	1885	95
„ „	The Effect of Sea Water on Portland Cement.	1888	39
„ „	Forced Filtration of Water Through Concrete.	1889	107
Fell, J. C.	Soft *v.* Hard Water for Manufacturing Purposes.	1884	103
Ferrar, W. G.	Practical Construction in the Colonies	1875	53
Fox, St. G. Lane ..	The Lighting and Extinction of Street Gas Lamps by Electricity.	1878	105
Fox, W. H.	Continuous Railway Brakes	1872	112
„ „	Continuous Railway Brakes	1873	33
Fraser, A.	The Use of the Cornish Pumping Engine.	1864	78
G.			
Gandon, C.	President's Address	1885	1
„ „	Gas Engines	1881	27
Gibbs, J. D.	The Distribution of Electrical Energy by Secondary Generators.	1885	49
Gore, H.	Modern Gas Works at Home and Abroad.	1868	233
„ „	Horse Railways and Street Tramways	1873	113
Graham, J.	The most Recent Improvements on the Injector.	1867	266
Greig, A.	Dundee Street Improvements and Drainage of Lochee.	1883	113

Author.	Subject of Paper.	Transactions. Year.	Page.
Gresham, J.	The most Recent Improvements on the Injector.	1867	266
Grierson, F. W. ..	The National Value of Cheap Patents	1880	145
Griffin, S.	Modern Gas-Engine Practice	1889	169
H.			
Hakewill, H.	Circular Tables	1865	147
Hall, C. E.	The Conversion of Peat into Fuel and Charcoal.	1876	151
„ „	Modern Machinery for Preparing Macadam for Roads.	1879	51
Hartley, F. W. ..	Methods employed in the Determination of the Commercial Value and the Purity of Coal Gas.	1869	100
„ „	An Improved Method of Charging and Drawing Gas Retorts.	1875	185
Hooper, H. R.	The Practice of Foundry Work	1888	191
Horner, J. G.	Certain Methods of Applying Screw Piles in a Bridge at Verona.	1867	52
Horsley, C.	President's Address	1881	1
Hutton, R. J.	The Stability of Chimney Shafts ..	1887	150
J.			
Jacob, A.	The Designing and Construction of Storage Reservoirs.	1866	225
Jensen, P.	Incrustation in Marine Boilers	1866	117
„ „	Friction in Steam Cylinders	1870	17
Jerram, G. B.	River Pollution caused by Sewage Disposal.	1886	217
Jones, A. W.	Modern Tramway Construction	1879	179
Justice, P. S.	The Dephosphorisation of Iron in the Puddling Furnace.	1885	189
K.			
King, G.	Irrigation with Town Sewage	1865	84
Kinsey, W. B.	The Arrangement, Construction, and Machinery of Breweries.	1881	173
Knapp, H. F.	Harbour Bars: their Formation and Removal.	1878	139
Kochs, W. E.	Strength and Rigidity	1865	69
L.			
Lailey, C. N.	Acton Main Drainage Works	1888	125
Latham, B.	President's Address	1868	1
„ „	President's Address	1871	1
„ „	The Drainage of the Fens	1862	154
„ „	The Inundations of Marsh Lands ..	1862	173
„ „	The Supply of Water to Towns ..	1864	199

Author.	Subject of Paper.	Transactions. Year.	Page.
LATHAM, B.	Utilisation of Sewage	1866	68
„ „	The Application of Steam to the Cultivation of the Soil.	1868	274
„ „	Ventilation of Sewers	1871	39
LAWFORD, G. M. ..	Fireproof Floors	1889	43
LAWFORD, W.	Light Railways	1888	181
LE FEUVRE, W. H. ..	President's Address	1867	1
LE GRAND, A.	Tube Wells	1877	133
LIGHT, C. J...	The Need of further Experiments on the Strength of Materials.	1869	194
„ „	A new Method of setting-out the Slopes of Earthworks.	1873	216
„ „	Opening Bridges on the Furness Railway.	1885	119
LIGHTFOOT, T. B. ..	Refrigerating Machinery on Board Ship.	1887	105
LOUCH, J.	Surface Condensers	1861	96
M.			
MACGEORGE, W.	President's Address	1874	1
MAJOR, W.	The Priming of Steam-Boilers	1877	59
MARTIN, W.	The Strength of Flues in Lancashire and similar Boilers.	1882	157
MARTIN, W. A.	Induced *v.* Forced Draught for Marine Boilers.	1886	111
MATHESON, E.	The Quality of Iron, as now used ..	1867	168
„ „	The Accumulator Cotton Press	1868	264
MAUDE, T.	The Government Brake Trials	1875	129
MCNAUGHT, W.	The Rolling of Ships..	1876	187
MOORE, L. G.	The Explosion at Erith, and the Repair of the River Bank.	1864	183
N.			
NURSEY, P. F.	President's Address	1886	1
„ „	The Superheating of Steam, and the various Apparatus employed therein.	1861	36
„ „	Steam Boiler Explosions	1863	1
„ „	Fuel	1864	1
„ „	Sugar-making Machinery	1865	155
„ „	Explosive Compounds for Engineering Purposes.	1869	10
„ „	English and Continental Intercommunication.	1869	154
„ „	Recent Improvements in Explosive Compounds.	1871	108
„ „	Economic Uses of Blast Furnace Slag	1873	196
„ „	Mechanical Puddling	1874	77
„ „	The Channel Railway	1876	17
„ „	Illumination by means of Compressed Gas.	1881	57
„ „	Modern Bronze Alloys for Engineering Purposes.	1884	127

Author.	Subject of Paper.	Transactions. Year.	Page.
Nursey, P. F.	Primary Batteries for Illuminating Purposes.	1887	185
„ „	Recent Developments in High Explosives.	1889	71
„ „	Fox's Patent System of Solid-pressed Steel Waggon and Carriage Frames.	1889	197
O.			
Oates, A.	The Utilisation of Tidal Energy ..	1882	81
Olander, E.	The Enclosure of Lands from the Sea, and the Construction of Sea and other Banks.	1862	25
„ „	Bridge Floors: Their Design, Strength, and Cost.	1887	27
Olrick, H.	A new System of Treating Sewage Matter.	1883	23
Olrick, L.	Marine Governors..	1862	104
„ „	Giffard's Injector..	1865	280
P.			
Page, G. G.	The Construction of Chelsea Bridge..	1863	77
Parkes, M.	The Road Bridges of the Charing Cross Railway.	1864	143
„ „	The Charing Cross Railway Bridge over the Thames.	1864	166
Parsey, W.	Trussed Beams	1862	52
Pearse, J. W.	The Ventilation of Buildings	1876	97
„ „	The Mechanical Firing of Steam Boilers.	1877	31
„ „	Water Purification, Sanitary and Industrial.	1878	29
Pendred, H. W.	Screw Propellers, their Shafts and Fittings.	1875	151
„ „	Distilling and Hoisting Machinery for Sea-going Vessels.	1880	55
„ „	Designs, Specifications, and Inspection of Ironwork.	1883	87
Pendred, V.	President's Address	1876	1
„ „	Elastic Railway Wheels	1864	119
„ „	The Adhesion of Locomotive Engines, and certain Expedients for increasing or supplementing that Function.	1865	207
„ „	Water-tube Boilers	1867	109
„ „	Apparatus for Measuring the Velocity of Ships.	1869	215
„ „	Examples of Recent Practice in American Locomotive Engineering.	1872	19
Perrett, E...	Filtration by Machinery	1888	106
Phillips, J.	The Forms and Construction of Channels for the Conveyance of Sewage.	1874	145
Pieper, C.	Ice-making Machinery	1882	139

Author.	Subject of Paper.	Transactions. Year.	Page.
R.			
Reade, S. A.	The Redhill Sewage Works	1868	168
Redman, J. B.	Tidal Approaches and Deep Water Entrances.	1885	143
Rigg, A.	President's Address	1884	1
„ „	The Connection between the Shape of heavy Guns and their Durability.	1867	249
„ „	The Screw Propeller	1868	202
„ „	Sensitiveness and Isochronism in Governors.	1880	73
„ „	American Engineering Enterprise	1885	21
„ „	Obscure Influences of Reciprocation in High-speed Engines.	1886	83
Riley, E.	The Action of Peaty Water on a Boiler	1862	45
„ „	The Manufacture of Iron	1861	59
Roberts, W.	Steam Fire-engines, and the late Trials at the Crystal Palace.	1863	163
Robinson, H.	President's Address	1887	1
„ „	Sewage Disposal	1879	197
Rumble, T. W.	Armour Plates	1861	87
Rymer-Jones, T. M.	Railway Tunnelling in Japan	1882	101
S.			
Sanderson, C.	The Bombay, Baroda, and Central India Railway.	1863	97
Sefi, M.	The Theory of Screw Propulsion	1870	82
Somerville, J.	Charging and Drawing Gas Retorts by Machinery.	1873	138
Spencer, G.	State Railways and Railway Amalgamation.	1872	43
Spice, R. P.	President's Address	1878	1
„ „	President's Address	1879	1
„ „	Some Modern Improvements in the Manufacture of Coal Gas.	1886	131
Spon, E.	The Use of Paints as an Engineering Material.	1875	69
Standfield, J.	Floating Docks—the Depositing Dock, and the Double-power Dock.	1881	81
Steel, J.	Air Compression	1876	65
Stephenson, W. H.	Fire-clay Manufactures	1861	17
Stopes, H.	The Engineering of Malting	1884	65
Strachan, G. R.	The Construction and Repair of Roads	1889	17
Suckling, N. J.	Modern Systems of Generating Steam	1874	39
Sugg, W.	Apparatus employed for Illumination with Coal Gas.	1869	134
Sutcliff, R.	Tube Wells for large Water Supplies	1877	149
Schönheyder, W.	Equalising the Wear in Horizontal Steam Cylinders.	1878	45
T.			
Tarbutt, P. F.	Liquid Fuel	1886	193
Thrupp, E. C.	A New Formula for the Flow of Water in Pipes and Open Channels.	1887	224

Author.	Subject of Paper.	Transactions. Year.	Page.
Trewman, H. C.	Flues and Ventilation	1876	91
Turner, C.	The Timbering of Trenches and Tunnels.	1871	90
Tweddell, R. H. ..	Direct-Acting Hydraulic Machinery..	1877	95
U.			
Usill, G. W.	Rural Sanitation	1877	113
V.			
Varley, S. A.	Railway Train Intercommunication ..	1873	162
W.			
Walmisley, A. T. ..	President's Address	1888	1
„ „ ..	Iron Roofs	1881	123
Wanklyn, J. A.	Cooper's Coal-liming Process	1884	167
Ward, G. M.	The Utilisation of Coal Slack in the Manufacture of Coke for Smelting.	1880	33
Walker, J.	Brewing Apparatus	1871	29
Warren, A.	Steam Navigation on the Indus ..	1863	139
Wessely, C. R. von ..	Arched Roofs	1866	36
Wilkins, T...	The Machinery and Utensils of a Brewery.	1871	10
Wilson, A. F.	The Manufacture of Coal Gas	1864	35
Wilson, J. W., junr. ..	The Construction of Modern Piers ..	1875	29
Wise, F.	Signalling for Land or Naval Purposes.	1863	117
Wise, W. L.	The Patent Laws	1870	45
Worssam, S. W., junr.	Mechanical Saws	1867	196
Y.			
Yarrow, A. F.	Steam Carriages	1862	128
Young, C. F. T.	The Use of Coal in Furnaces without Smoke.	1862	66

SUBJECTS.

Subject of Paper.	Author.	Transactions. Year.	Page.
A.			
Accumulator Cotton Press	E. Matheson	1868	264
Action of Peaty Water on a Boiler ..	E. Riley	1862	45
Action of Marine Worms and Remedies employed in the Harbour of San Francisco.	J. Blackbourn	1874	111
Acton Main Drainage Works	C. N. Lailey	1888	125
Address of President	W. T. Carrington ..	1865	1
„ „	Z. Colburn	1866	1
„ „	W. H. Le Feuvre ..	1867	1
„ „	B. Latham	1868	1
„ „	F. W. Bryant	1869	1
„ „	W. Adams	1870	1
„ „	B. Latham	1871	1
„ „	J. Church	1872	1
„ „	„ „	1873	1
„ „	W. Macgeorge	1874	1
„ „	J. H. Adams	1875	1
„ „	V. Pendred	1876	1
„ „	T Cargill	1877	1
„ „	R. P. Spice	1878	1
„ „	„ „	1879	1
„ „	J. Bernays	1880	1
„ „	C. Horsley	1881	1
„ „	J. Church	1882	1
„ „	„ „	1883	1
„ „	A. Rigg	1884	1
„ „	C. Gandon	1885	1
„ „	P. F. Nursey	1886	1
„ „	Professor H. Robinson	1887	1
„ „	A. T. Walmisley ..	1888	1
„ „	J. R. Baillie	1889	1
Adhesion of Locomotive Engines and certain Expedients for Increasing or Supplementing that Function.	V. Pendred	1865	207
Air Compression	J. Steel	1876	65
American Engineering Enterprise ..	A. Rigg	1885	21
American Locomotive Engineering, Examples of recent Practice in	V. Pendred	1872	19
Apparatus for utilising the Waste Heat of Exhaust Steam.	J. Atkinson	1878	167
Apparatus for Measuring the Velocity of Ships.	V. Pendred	1869	15

Subject of Paper.	Author.	Transactions. Year.	Page.
Apparatus employed for Illumination with Coal Gas.	W. Sugg	1869	134
Application of Steam to the Cultivation of the Soil.	B. Latham	1868	274
Arched Roofs	C. von Wessely	1866	36
Armour Plates	T. W. Rumble	1861	87
Arrangement, Construction, and Machinery of Breweries.	W. B. Kinsey	1881	173
Axles, The Strength of Wrought-iron Railway	T. Andrews	1879	143
B.			
Batteries, Primary, for Illuminating Purposes.	P. F. Nursey	1887	185
Blast-furnace Slag, The Economic Uses of	„ „	1873	196
Blasting Charges, The Application of Electricity to the Ignition of	G. G. André	1878	123
Blow-pipe Flame Furnace	A. C. Engert	1884	185
Boilers, Incrustation in Marine	P. Jensen	1866	117
Boilers, Strength of Flues in Lancashire and similar	W. Martin	1882	157
Boilers, The Defects of Steam, and their Remedy.	A. C. Engert	1884	25
Boilers, The Mechanical Firing of Steam	J. W. Pearse	1877	31
Boilers, The Priming of Steam	W. Major	1877	59
Boilers, Water and its Effects on Steam	H. K. Bamber	1867	65
Boilers, Water Tube	V. Pendred	1867	109
Bombay, Baroda, and Central India Railway.	C. Sanderson	1863	97
Brake Trials, The Government	T. Maude	1875	129
Brakes, Continuous Railway	W. H. Fox	1872	112
„ „	„ „	1873	33
Brakes, Hydraulic Continuous and Automatic.	E. D. Barker	1879	75
Brakes, Recent Arrangements of Continuous	St. J. V. Day	1875	87
Breakwaters, Floating	T. Cargill	1871	146
Breweries, the Arrangement, Construction, and Machinery of	W. B. Kinsey	1881	173
Brewery, Machinery and Utensils of a	T. Wilkins	1871	10
Brewing Apparatus	J. Walker	1871	29
Bridge, Railway, at the Place de l'Europe, Paris.	T. Cargill	1866	191
Bridge Floors: Their Design, Strength and Cost.	E. Olander	1887	27
Bridge, Construction of Chelsea	G. G. Page	1863	77
Bridge over the Thames, Charing Cross Railway	M. Parkes	1864	166
Bridges of the Charing Cross Railway, The Road	„ „	1864	143

Subject of Paper.	Author.	Transactions. Year.	Page.
Bridges, Opening, on the Furness Railway.	C. J. Light	1885	119
Bronze Alloys for Engineering Purposes, Modern	P. F. Nursey	1884	127
Buildings, The Ventilation of	J. W. Pearse	1876	97
C.			
Cable Tramways	W. N. Colam	1885	69
Canal between the Atlantic and Pacific Oceans, The Surveys of Proposed Lines for a Ship	Dr. E. Cullen	1868	15
Canal, The Isthmus of Darien and the Ship	„ „	1868	52
Carriage Frames, Fox's Patent System of Solid pressed Steel Waggon and	P. F. Nursey	1889	197
Carriages, Steam	A. F. Yarrow	1862	128
Cast-iron, Certain Methods of Treating, in the Foundry.	Z. Colburn	1865	77
Cement, Portland	H. Faija	1885	95
Central India Railway, Bombay, Baroda, and	C. Sanderson	1863	97
Channel Railway, The	P. F. Nursey	1876	17
Channels for the Conveyance of Sewage, The Forms and Construction of	J. Phillips	1874	145
Charcoal, The Conversion of Peat into Fuel and	C. E. Hall	1876	151
Charging and Drawing Gas Retorts by Machinery.	J. Somerville	1873	138
Charging and Drawing Gas Retorts, An Improved Method of	F. W. Hartley	1875	185
Charing Cross Railway Bridge over the Thames.	M. Parkes	1864	166
Charing Cross Railway, The Road Bridges of	„ „	1864	143
Cheap Patents, The National value of	F. W. Grierson	1880	145
Chelsea Bridge, The Construction of ..	G. G. Page	1863	77
Chimney Shafts, Stability of	R. J Hutton	1887	150
Circular Tables	H. Hakewill	1865	147
Coal Gas, The methods employed in the determination of the Commercial Value and Purity of	F. W. Hartley	1869	100
Coal Gas, Apparatus employed for illumination with	W. Sugg	1869	134
Coal Gas, The Manufacture of	A. F. Wilson	1864	35
Coal Gas, Some Modern Improvements in the Manufacture of	R. P. Spice	1886	131
Coal-liming Process, Cooper's	J. A. Wanklyn	1884	167
Coal Mines, The Ventilation of	G. G. André	1874	23
Coal Slack, Utilisation of, in the Manufacture of Coke for Smelting.	G. M. Ward	1880	33
Colliery, The Underground Pumping Machinery at the Erin, Westphalia	H. Davey	1876	119
Colonies, Practical Construction in the	W. G. Ferrar	1875	53

Subject of Paper.	Author.	Transactions. Year.	Page.
Compressed Gas, Illumination by means of	P. F. Nursey	1881	57
Compression, Air	J. Steel	1876	65
Concrete, Forced Filtration of Water Through	H. Faija	1889	107
Condensers, Surface	J. Louch	1861	96
Connection between the Shape of Heavy Guns and their Durability.	A. Rigg	1867	249
Construction, The, and Repair of Roads	G. R. Strachan	1889	17
Construction, Modern Tramway	A. W. Jones	1879	79
Construction, Modern Roadway	H. S. Copland	1878	61
Construction of Chelsea Bridge	G. G. Page	1863	77
Construction of Modern Piers	J. W. Wilson, junr. ..	1875	29
Continental Intercommunication, English and	P. F. Nursey	1869	154
Continuous and Automatic Brakes, Hydraulic	E. D. Barker	1879	75
Continuous Brakes, Recent arrangements of	St. J. V. Day	1875	87
Continuous Railway Brakes	W. H. Fox	1872	112
,, ,, ,, ...	,, ,, ...	1873	33
Conversion of Peat into Fuel and Charcoal	C. E. Hall	1876	151
Cooper's Coal-liming Process	J. A. Wanklyn	1884	167
Cornish Pumping Engine, The Use of the	A. Fraser	1864	78
Cotton Press, The Accumulator	E. Matheson	1868	264
Cylinders, Equalising the wear in Horizontal Steam	W. Schönheyder ..	1878	45
Cylinders, Friction in Steam	P. Jensen	1870	17
Cyprus, Engineering Notes on	C. J. Alford	1880	131
D.			
Darien and the Ship Canal, The Isthmus of	Dr. E. Cullen	1868	52
Deep-Sea Lighthouses, Feasibility, and Construction of	C. Anderson	1883	45
Deep-water Entrances, Tidal Approaches and	J. B. Redman	1885	143
Defects of Steam Boilers and their Remedy.	A. C. Engert	1884	25
Dephosphorisation of Iron in the Puddling Furnace.	P. S. Justice	1885	169
Design, Strength, and Cost of Bridge Floors.	E. Olander	1887	27
Designing and Construction of Storage Reservoirs, The	A. Jacob	1866	225
Designs, Specifications, and Inspection of Ironwork	H. W. Pendred	1883	87
Direct-acting Hydraulic Machinery ..	R. H. Tweddell	1877	95
Direct-acting Pumping Engines ..	P. B. Björling	1877	79
Disposal of Sewage, The	H. Robinson	1879	197
Distilling and Hoisting Machinery for Sea-going Vessels.	H. W. Pendred	1880	55

Subject of Paper.	Author.	Transactions. Year.	Page.
Distribution of Electrical Energy by Secondary Generators.	J. D. Gibbs	1885	49
Docks, Floating.—The Depositing Dock and the Double-power Dock.	J. Standfield	1881	81
Drainage and Water Supply to the Town of Fareham.	T. Buckham	1869	41
Drainage Works, Main, Acton	C. N. Lailey	1888	125
Drainage of the Fens, The	B. Latham	1862	154
Dundee Street Improvements and Drainage of Lochee.	A. Greig	1883	113
E.			
Earthworks, A New Method of setting out the Slopes of	C. J. Light	1873	216
Economics of Railway Maintenance ..	E. S. Crompton	1870	101
Economic Uses of Blast Furnace Slag	P. F. Nursey	1873	196
Effect of Sea Water on Portland Cement	H. Faija	1888	39
Elastic Railway Wheels	V. Pendred	1864	119
Electric Light Engineering, Notes on ..	C. H. W. Biggs and W. W. Beaumont	1882	23
Electric Telegraph Instruments	E. G. Bartholomew ..	1872	53
Electric Telegraphy, irrespective of Telegraphic Apparatus.	„ „ ..	1869	55
Electrical Batteries	„ „ ..	1872	77
Electrical Energy, Distribution of, by Secondary Generators.	J. D. Gibbs	1885	49
Electricity, The application of, to the ignition of Blasting Charges.	G. G. André	1878	123
Electricity, The Lighting and Extinction of Street Gas Lamps by	St. G. Lane Fox ..	1878	105
Enclosure of Lands from the Sea, and the Construction of Sea and other banks.	E. Olander	1862	25
Engineering Enterprise, American ..	A. Rigg	1885	21
Engineering Notes on Cyprus	C. J. Alford	1880	131
Engineering in India	F. C. Danvers	1868	137
Engineering of Malting	H. Stopes	1884	65
Engines, Direct-acting Pumping	P. B. Björling	1877	79
Engines for Mines, Recent Improvements in Pumping	H. Davey	1873	182
Engines for Town Water Supply, Pumping	„ „	1867	88
Engines, Gas	C. Gandon	1881	27
Engines, Obscure Influences of Reciprocation in High Speed	A. Rigg	1886	83
Engines on the Rimutakai Incline, New Zealand, The Fell	R. J. Alford	1882	121
Engines, Steam Fire, and the late trial at the Crystal Palace.	W. Roberts	1863	163
Engines, The Adhesion of Locomotive, and certain expedients for increasing or supplementing that Function.	V. Pendred	1865	207
Engines, The Use of the Cornish Pumping	A. Fraser	1864	78

Subject of Paper.	Author.	Transactions. Year.	Page.
English and Continental Intercommunication.	P. F. Nursey	1869	154
Equalising the Wear in Horizontal Steam Cylinders.	W. Schönheyder ..	1878	45
Examples of Recent Practice in American Locomotive Engineering.	V. Pendred	1872	19
Exhaust Steam, Apparatus for Utilising the Waste Heat of	J. Atkinson	1878	167
Exhibitions as Aids to Engineering Progress, Value of The	S. Barnett, junr. ..	1883	75
Experimental Researches into the Nature and Action of Steam Boilers.	T. Baldwin	1867	23
Experiments on the Strength of Materials, The Need of further	C. J. Light	1869	194
Explosion at Erith, and the Repair of the River Bank.	L. G. Moore	1864	183
Explosions, Steam Boiler	P. F. Nursey	1863	1
Explosive Compounds for Engineering Purposes.	„ „	1869	10
Explosive Compounds, Recent Improvements in	„ „	1871	108
Explosives, High, Recent Developments in	„ „	1889	75
F.			
Fareham, Drainage and Water Supply of the Town of	T. Buckham	1869	41
Feasibility and Construction of Deep-sea Lighthouses.	C. Anderson	1883	45
Fell Engines on the Rimutakai Incline, New Zealand.	R. J. Alford	1882	121
Fens, The Drainage of the	B. Latham	1862	154
Filtration by Machinery	E. Perrett	1888	106
Filtration, Forced, of Water through Concrete	H. Faija	1889	107
Fire-clay Manufactures	W. H. Stevenson ..	1861	17
Fire Engines, Steam	W. Roberts	1863	163
Fireproof Floors	G. M. Lawford	1889	43
Floating Breakwaters	T. Cargill	1871	146
Floating Docks: The Depositing Dock and the Double-power Dock.	J. Standfield	1881	81
Floors, Fireproof	G. M. Lawford	1889	43
Flow of Water, New Formula for, in Pipes and Open Channels.	E. C. Thrupp	1887	224
Flues and Ventilation	A. H. C. Trewman ..	1876	91
Flues in Lancashire and similar Boilers, The Strength of	W. Martin	1882	157
Forms and Construction of Channels for the Conveyance of Sewage.	J. Phillips	1874	145
Foundry Work, Practice of	H. R. Hooper	1888	191
Fox's Patent System of Solid-pressed Steel Waggon and Carriage Frames.	P. F. Nursey	1889	197
Friction in Steam Cylinders	P. Jensen	1870	17

Subject of Paper.	Author.	Transactions. Year.	Page.
Friction of the Slide Valve and its Appendages.	T. Adams	1866	6
Fuel	P. F. Nursey	1864	1
Fuel and Charcoal, The Conversion of Peat into	C. E. Hall	1876	151
Fuel, Liquid	P. F. Tarbutt	1886	193
Furnace, The Blowpipe Flame	A. C. Engert	1884	185
G.			
Gas, Apparatus employed for Illumination with Coal	W. Sugg	1869	134
Gas Engines	C. Gandon	1881	27
Gas-Engine, Modern, Practice	S. Griffin	1889	169
Gas, Illumination by means of Compressed	P. F. Nursey	1881	57
Gas, Modern Improvements in the Manufacture of Coal	R. P. Spice	1886	131
Gas Retorts, An Improved Method of Charging and Drawing	F. W. Hartley	1875	185
Gas Retorts, Charging and Drawing by Machinery.	J. Somerville	1873	138
Gas, The Manufacture of Coal	A. F. Wilson	1864	35
Gas, The Methods employed in the determination of the Commercial Value and Purity of Coal	F. W. Hartley	1869	100
Gas and Water Mains, The Prevention of Leakage in	C. M. Barker	1869	79
Gas Works at Home and Abroad, Modern	H. Gore	1868	233
Giffard's Injector	L. Olrick	1865	280
Government Brake Trials	T. Maude	1875	129
Governors, Marine	L. Olrick	1862	104
Governors, Sensitiveness and Isochronism in	A. Rigg	1880	73
Guns, The connection between the Shape of Heavy, and their Durability.	„ „	1867	249
H.			
Harbour Bars: their Formation and Removal.	H. F. Knapp	1878	139
Hauling Machinery, The new Pit and, for the San Domingos Mine in Portugal.	J. Bernays	1879	29
High Pressure Steam and Steam Engine Efficiency.	W. W. Beaumont ..	1888	221
Horse Railways and Street Tramways.	H. Gore	1873	113
Hydraulic Continuous and Automatic Brakes.	E. D. Barker	1879	75
Hydraulic Experiments, the Roorkee ..	E. S. Bellasis	1886	41
Hydraulic Machinery, Direct-acting ..	R. H. Tweddell	1877	95

Subject of Paper.	Author.	Transactions. Year.	Page.
I.			
Ice-making Machinery	C. Pieper	1882	139
Ignition of Blasting Charges, The application of Electricity to	G. G. André	1878	123
Illumination by means of Compressed Gas.	P. F. Nursey	1881	57
Illumination with Coal Gas, Apparatus employed for	W. Sugg	1869	134
Improved Method of Charging and Drawing Gas Retorts.	F. W. Hartley	1875	185
Improvements in Explosive Compounds, Recent	P. F. Nursey	1871	108
Improvements in Pumping-engines for Mines, Recent	H. Davey	1873	182
Improvements in Tin Dressing Machinery, Recent	S. H. Cox	1874	11
Incrustation in Marine Boilers	P. Jensen	1866	117
India, Engineering in	F. C. Danvers	1868	137
Induced *v.* Forced Draught for Marine Boilers.	W. A. Martin	1886	111
Indus, Steam Navigation on the	A. Warren	1863	139
Injector, Giffard's	L. Olrick	1865	280
Injector, The most Recent Improvements on the	J. Gresham	1867	266
Instruments, Electric Telegraph	E. G. Bartholomew ..	1872	53
Intercommunication, English and Continental	P. F. Nursey	1869	154
Intercommunication, Railway Train ..	S. A. Varley	1873	162
International System of Marine Course Signalling.	Capt. W. B. Barker ..	1884	47
Inundations of Marsh Land	B. Latham	1862	173
Iron, The Dephosphorisation of, in the Puddling Furnace.	P. S. Justice	1885	169
Iron, The Manufacture of	E. Riley	1861	59
Iron, The relation between the Safe Load and ultimate Strength of	Z. Colburn	1863	35
Iron, The quality of, as now used ..	E. Matheson	1867	168
Iron Roofs	A. T. Walmisley ..	1881	123
Iron and Steel Surfaces, The Preservation and Ornamentation of	G. Bower	1883	59
Ironwork, Designs, Specifications, and Inspection of	H. W. Pendred	1883	87
Irrigation with Town Sewage	G. King	1865	84
Isochronism in Governors, Sensitiveness and	A. Rigg	1880	73
Isthmus of Darien and the Ship Canal	Dr. E. Cullen	1868	52
J.			
Japan, Railway Tunnelling in	T. M. Rymer-Jones ..	1881	101
Joints, Single- and Double-rivetted ..	T. Baldwin	1866	150

Subject of Paper.	Author.	Transactions. Year.	Page.
L.			
Land and Naval Purposes, Signalling for	F. Wise	1863	117
Lartigue Single-rail Railway, The ..	F. B. Behr	1886	163
Laws, Decrees and Regulations relating to Mining Operations in the old kingdom of Sardinia.	C. J. Alford	1879	106
Leakage in Gas and Water Mains, The prevention of	C. M. Barker	1869	79
Light Railways	W. Lawford	1888	181
Lighthouses, The feasibility and construction of Deep-sea	C. Anderson	1883	45
Lighting and Extinction of Street Gas-Lamps by Electricity.	St. G. Lane Fox ..	1878	105
Liquid Fuel	P. F. Tarbutt	1886	193
Lochee, Dundee Street Improvements and Drainage of	A. Greig	1883	113
Locomotive Engineering, Examples of recent Practice in American	V. Pendred..	1872	19
Locomotive Engines, The adhesion of..	„ „	1865	207
M.			
Macadam for Roads, Modern Machinery for preparing	C. E. Hall	1879	51
Machinery, Refrigerating, on Board Ship.	T. B. Lightfoot	1887	105
Machinery, Filtration by	E. Perrett	1888	106
Machinery and Utensils of a Brewery..	T. Wilkins	1871	10
Main Drainage and Sewage Disposal Works, Wimbledon	W. S. Crimp	1888	73
Main Drainage Works, Acton	C. N. Lailey.	1888	125
Maintenance, The Economics of Railway	E. S. Crompton ..	1870	101
Malting, The Engineering of	H. Stopes	1884	65
Manufacture of Coal Gas	A. F. Wilson	1864	35
Manufacture of Iron	E. Riley	1861	59
Marine Boilers, Incrustation in	P. Jensen	1866	117
Marine Boilers, Induced *v.* Forced Draught for	W. A. Martin	1886	111
Marine Course Signalling, International system of	Capt. W. B. Barker ..	1884	47
Marine Governors	L. Olrick	1862	104
Marine Worms, Action of and Remedies for, at San Francisco.	J. Blackbourn	1874	111
Marsh Lands, The Inundations of ..	B. Latham	1862	173
Mechanical Firing of Steam Boilers ..	J. W. Pearse	1877	31
Mechanical Puddling	P. F. Nursey	1874	77
Mechanical Saws	S. W. Worssam, junr.	1867	196
Methods employed in the Determination of the Commercial Value and Purity of Coal Gas.	F. W. Hartley	1869	100

Subject of Paper.	Author.	Transactions. Year.	Page.
Milford Haven and its New Pier Works.	H. Davey	1872	89
Milling Machinery, Roller	J. H. Carter	1883	125
Mineralogy of the Island of Sardinia ..	C. J. Alford	1879	93
Mining Operations in the old kingdom of Sardinia, Laws, &c., relating to	„ „	1879	106
Modern Bronze Alloys for Engineering purposes.	P. F. Nursey	1884	127
Modern Gas-Engine Practice	S. Griffin	1889	169
Modern Gasworks at Home and Abroad	H. Gore	1868	233
Modern Improvements in the Manufacture of Coal Gas.	R. P. Spice	1886	131
Modern Roadway Construction	H. S. Copland	1878	61
Modern Steel as a Structural Material	W. W. Beaumont ..	1880	109
Modern Systems of Generating Steam	N. J. Suckling	1874	39
Modern Tramway Construction	A. W. Jones	1879	179
N.			
National Value of Cheap Patents ..	F. W. Grierson	1880	145
Navigation on the Indus, Steam	A. Warren	1863	139
Need of further Experiments on the Strength of Materials.	C. J. Light	1869	194
New Formula for the Flow of Water in Pipes and Open Channels.	E. C. Thrupp	1887	224
Notes on Cyprus, Engineering	C. J. Alford	1880	131
Notes on Electric Light Engineering ..	C. H. W. Biggs and W. W. Beaumont ..	1882	23
O.			
Obituary	.. ..	1887	265
„	.. ..	1888	253
„	.. ..	1889	219
Obscure Influences of Reciprocation in High-speed Engines.	A. Rigg	1886	83
Opening Bridges on the Furness Railway.	C. J. Light	1885	119
P.			
Paints, The Use of, as an Engineering Material.	E. Spon	1875	69
Panama Railroad, The	Dr. E. Cullen	1868	39
Paris Exhibition, Visit to the	.. ..	1867	151
Patent Laws, The	C. D. Abel	1865	25
„ „ „	W. L. Wise	1870	45
Patents, The National Value of Cheap	F. W. Grierson	1880	145
Peat, The Conversion of, into Fuel and Charcoal.	C. E. Hall	1876	151

Subject of Paper.	Author.	Transactions. Year.	Page.
Peaty water, The Action of, on a Boiler	E. Riley	1862	45
Piers, The Construction of Modern ..	J. W. Wilson, junr. ..	1875	29
Pier Works, Milford Haven and its New	H. Davey	1872	89
Pin-connected *v.* Rivetted Bridges ..	J. H. Cunningham ..	1889	131
Pits and Hauling Machinery for the San Domingos Mines in Portugal.	J. Bernays	1879	29
Portland Cement	H. Faija	1885	95
Portland Cement, Effect of Sea Water on	„ „	1888	39
Practical Construction in the Colonies	W. G. Ferrar	1875	53
Practice of Foundry Work	H. R. Hooper	1888	191
Preservation and Ornamentation of Iron and Steel Surfaces.	G. Bower	1883	59
Prevention of Smoke	A. C. Engert	1881	101
Prevention of Leakage in Gas and Water Mains.	C. M. Barker	1869	79
Primary Batteries for Illuminating Purposes.	P. F. Nursey	1887	185
Priming of Steam Boilers	W. Major	1877	59
Propeller, The Screw	A. Rigg	1868	202
Propellers, Screw; their Shafts and Fittings.	H. W. Pendred	1875	151
Propulsion, The Theory of Screw ..	M. Sefi	1870	82
Puddling Furnace, The Dephosphorisation of Iron in	P. S. Justice	1885	169
Puddling, Mechanical	P. F. Nursey	1874	77
Pumping Engine, The Use of the Cornish	A. Fraser	1864	78
Pumping Engines, Direct-acting ..	P. B. Björling	1877	79
Pumping Engines for Mines, Recent Improvements in	H. Davey	1873	182
Pumping Engines for Town Water Supply.	„ „	1867	88
Pumping Machinery, The Underground, at the Erin Colliery, Westphalia.	„ „	1876	119
Q.			
Quality of Iron, as now used	E. Matheson	1867	168
R.			
Railway Amalgamation, State Railways and	G. Spencer	1872	43
Railway Axles, The Strength of Wrought-iron	T. Andrews	1879	143
Railway Brakes, Continuous	W. H. Fox	1872	112
„ „ „	„ „	1873	33
Railway Bridge at the Place de l'Europe, Paris.	T. Cargill	1866	191
Railway Bridge over the Thames, The Charing Cross.	M. Parkes	1864	166

Subject of Paper.	Author.	Transactions. Year.	Page.
Railway Maintenance, The Economics of	E. S. Crompton	1870	101
Railway, The Channel	P. F. Nursey	1876	17
Railway Train Intercommunication ..	S. A. Varley	1873	162
Railway Tunnelling in Japan	T. M. Rymer-Jones ..	1882	101
Railway Wheels, Elastic	V. Pendred	1864	119
Railways, Horse, and Street Tramways	H. Gore	1873	113
Railways, Light	W. Lawford	1888	181
Recent Developments in High Explosives.	P. F. Nursey	1889	71
Reciprocation, Obscure Influences of, in High-speed Engines.	A. Rigg	1886	83
Redhill Sewage Works, The	S. A. Reade	1868	168
Refrigerating Machinery on Board Ship.	T. B. Lightfoot	1887	105
Relation between the Safe Load and ultimate Strength of Iron.	Z. Colburn	1863	35
Renewal of Roof over Departure Platform at King's Cross Terminus, G.N.R.	R. M. Bancroft	1887	125
Repair of the River Bank, The Explosion at Erith and the	L. G. Moore	1864	183
Reservoirs, Storage, The Designing and Construction of	A. Jacob	1866	225
Rigidity, Strength and	W. E. Kochs	1865	69
River Pollution caused by Sewage Disposal.	G. B. Jerram	1886	217
Rivetted, Pin-connected Bridges *v.* ..	J. H. Cunningham ..	1889	135
Road Bridges of the Charing Cross Railway.	M. Parkes	1864	143
Roads, The Construction and Repair of	G. R. Strachan	1889	17
Roadway Construction, Modern	H. S. Copland	1878	61
Roller-milling Machinery	J. H. Carter	1883	125
Rolling of Ships	W. McNaught	1876	187
Roof, Renewal of, over Departure Platform at King's Cross Terminus, G.N.R.	R. M. Bancroft	1887	125
Roofs, Arched	C. R. von Wessely ..	1866	36
Roofs, Iron	A. T. Walmisley ..	1881	123
Roorkee Hydraulic Experiments	E. S. Bellasis	1886	41
Rural Sanitation	G. W. Usill	1877	113
S.			
Safe Load and Ultimate Strength of Iron, Relation between	Z. Colburn	1863	35
Safety Valves for Steam Boilers, &c. ..	T. Baldwin	1867	23
Sanitary and Industrial, Water Purification	J. W. Pearse	1878	29
Sardinia, The Mineralogy of the Island of	C. J. Alford	1879	93
Saws, Mechanical	S. W. Worssam, junr.	1867	196
Screw Piles in the Construction of a Wrought-iron Bridge at Verona.	J. G. Horner	1867	52
Screw Propeller, The	A. Rigg	1868	202
Screw Propellers, their Shafts and Fittings.	H. W. Pendred	1875	151

Subject of Paper.	Author.	Transactions. Year.	Page.
Screw Propulsion, The Theory of ..	M. Sefi	1870	82
Sea and other Banks, The Construction of	E. Olander	1862	25
Sea Water, Effect of, on Portland Cement.	H. Faija	1888	39
Secondary Generators, Distribution of Electrical Energy by	J. D. Gibbs	1885	49
Sensitiveness and Isochronism in Governors.	A. Rigg	1880	73
Sewage Disposal	H. Robinson	1879	197
Sewage Disposal, River Pollution caused by	G. B. Jerram	1886	217
Sewage Disposal Works, and Main Drainage, Wimbledon.	W. S. Crimp	1888	73
Sewage, Irrigation with Town	G. King	1865	84
Sewage Matter, A new System of treating	H. Olrick	1883	23
Sewage, The Forms and Construction of Channels for the Conveyance of	J. Phillips	1874	145
Sewage, Utilisation of	B. Latham	1866	68
Sewage Works, Redhill	S. A. Reade	1868	168
Sewerage System, The Shone Hydro-Pneumatic.	E. Ault	1887	68
Sewers, Ventilation of	B. Latham	1871	39
Ship Canal between the Atlantic and Pacific Oceans, The Surveys for	Dr. E. Cullen	1868	15
Ship Canal, The Isthmus of Darien and the	„ „	1868	52
Ships, Apparatus for Measuring the Velocity of	V. Pendred	1869	215
Ships, The Rolling of	W. McNaught	1876	187
Shone Hydro-Pneumatic Sewerage System.	E. Ault	1887	68
Signalling for Land and Naval purposes	F. Wise	1863	117
Single and Double-rivetted Joints ..	T. Baldwin	1866	150
Slag, The Economic Use of Blast-furnace	P. F. Nursey	1873	196
Slide-valve, The Friction of, and its appendages.	T. Adams	1866	6
Slopes of Earthwork, A new Method of Setting-out.	C. J. Light	1873	216
Smoke, Prevention of	A. C. Engert	1881	101
Soft *v.* Hard Water for Manufacturing purposes.	J. C. Fell	1884	103
Soil, Application of Steam to the Cultivation of the	B. Latham	1868	274
Stability of Chimney Shafts	R. J. Hutton	1887	150
State Railways and Railway Amalgamation.	G. Spencer	1872	43
Steam, Apparatus for Utilising the Waste Heat of Exhaust	J. Atkinson	1878	167
Steam Boilers, The Defects of, and their Remedy.	A. C. Engert	1884	25
Steam Boiler Explosions	P. F. Nursey	1863	1

Subject of Paper.	Author.	Transactions. Year.	Page.
Steam Boilers, Experimental Researches into the Nature and Action of	T. Baldwin	1867	23
Steam Boilers, The Priming of	W. Major	1877	59
Steam Boilers, Mechanical Firing of ..	J. W. Pearse	1877	31
Steam Boilers, Water and its effect on	H. K. Bamber	1867	65
Steam Carriages	A. F. Yarrow	1862	128
Steam Cylinders, Equalising the Wear in Horizontal	W. Schönheyder ..	1878	45
Steam Cylinders, Friction in	P. Jensen	1870	17
Steam Fire Engines, and the late trial at the Crystal Palace.	W. Roberts..	1853	163
Steam, High Pressure, and Steam Engine Efficiency.	W. W. Beaumont ..	1888	221
Steam, Modern Systems of Generating	N. J. Suckling	1874	39
Steam Navigation on the Indus	A. Warren	1863	139
Steel, Modern, as a Structural Material	W. W. Beaumont ..	1880	109
Steel Waggon and Carriage Frames, Fox's System of Solid-pressed	P. F. Nursey	1889	197
Stone-sawing Machinery	H. Conradi..	1876	135
Storage Reservoirs, Designing and Construction of	A. Jacob	1866	225
Street Tramways, Horse Railways and	H. Gore	1873	113
Strength and Rigidity	W. E. Kochs	1865	69
Strength of Flues in Lancashire and similar Boilers.	W. Martin	1882	157
Strength of Materials, Need of further Experiments on the	C. J. Light..	1869	194
Strength of Wrought-iron Railway Axles.	T. Andrews	1879	143
Sugar-making Machinery	P. F. Nursey	1865	155
Super-heating of Steam, and the various Appliances employed therein.	„ „	1861	36
Supply of Water to Towns	B. Latham	1864	199
Surface Condensers	J. Louch	1861	96

T.

Tables, Circular	H. Hakewill	1865	147
Telegraph Instruments, Electric	E. G. Bartholomew ..	1872	53
Telegraphy, Electric, irrespective of Telegraphic apparatus.	„ „ ..	1869	55
Testimonial to Mr. Alfred Williams ..	.. ..	1868	161
Theory of Screw Propulsion	M. Sefi	1870	82
Tidal Approaches and Deep-water Entrances.	J. B. Redman	1885	143
Tidal Energy, Utilisation of	A. Oates	1882	81
Timbering of Trenches and Tunnels ..	C. Turner	1871	90
Tin-dressing Machinery, Recent Improvements in	S. H. Cox	1874	11
Town Sewage, Irrigation with	G. King	1865	84
Towns, Supply of Water to	B. Latham	1864	199
Town Water Supply, Pumping Engines for	H. Davey	1867	88

Subject of Paper.	Author.	Transactions. Year.	Page.
Tramway Construction, Modern	A. W. Jones	1879	179
Tramway Rolling Stock, and Steam in connection therewith.	C. C. Cramp	1874	119
Tramways, Cable	W. N. Colam	1885	69
Treating Sewage Matter, A new system of	H. Olrick	1883	23
Trussed Beams	W. Parsey	1862	52
Tube Wells	A. Le Grand	1877	133
Tube Wells for large Water Supply ..	R. Sutcliff	1877	149
Tunnelling, Railway, in Japan	T. M. Rymer-Jones ..	1882	101
Tunnels, Timbering of Trenches and ..	C. Turner	1871	90
U.			
Underground Pumping Machinery at the Erin Colliery, Westphalia.	H. Davey	1876	119
Use of Coal in Furnaces without Smoke	C. F. T. Young	1862	66
Utensils of a Brewery, Machinery and	T. Wilkins	1871	10
Utilisation of Coal Slack in the Manufacture of Coke for Smelting.	G. M. Ward	1880	33
Utilisation of Sewage	B. Latham	1866	68
Utilisation of Tidal Energy	A. Oates	1882	81
Utilisation of Waste Mineral Substances.	E. Edwards	1861	82
V.			
Vacation Visits	.. ..	1878	119
„ „	.. ..	1879	141
„ „	.. ..	1880	89
„ „	.. ..	1881	121
„ „	.. ..	1882	119
„ „	..	1883	85
„ „	.. ..	1884	119
„ „	.. ..	1885	113
„ „	.. ..	1886	153
„ „	.. ..	1887	145
„ „	.. ..	1888	148
„ „	.. ..	1889	131
Value of Exhibitions as Aids to Engineering Progress.	S. Barnett, junr. ..	1883	75
Value of Cheap Patents, The National	E. W. Grierson	1880	145
Velocity of Ships, Apparatus for Measuring the	V. Pendred	1869	215
Ventilation, Flues and	A. H. C. Trewman ..	1876	91
Ventilation of Buildings	J. W. Pearse	1876	97
Ventilation of Coal Mines	G. G. André	1874	23
Ventilation of Sewers	B. Latham	1871	39
Verona, Screw Piles in the construction of wrought-iron Bridge at	J. G. Horner	1867	52
Visit to the Paris Exhibition	.. ..	1867	151

Subject of Paper.	Author.	Transactions. Year.	Page.
W.			
Waggon and Carriage Frames, Fox's Patent System of Solid-pressed Steel,	P. F. Nursey	1889	197
Waste Heat of Exhaust Steam, Apparatus for Utilising the	J. Atkinson	1878	167
Waste Mineral Substances, The Utilisation of	E. Edwards	1861	82
Water and its effects on Steam Boilers ..	H. K. Bamber	1867	65
Water Purification, Sanitary and Industrial.	J. W. Pearse	1878	29
Water, Soft *v.* Hard, for Manufacturing purposes.	J. C. Fell	1884	103
Water, Supply of, to Towns	B. Latham	1864	199
Water Supply, Pumping-engines for Town	H. Davey	1867	88
Water Supply to the Town of Fareham, Drainage and	T. Buckham	1869	41
Water-tube Boilers	V. Pendred	1867	109
Wear in Horizontal Steam Cylinders, Equalising the	W. Schönheyder ..	1878	45
Wells, Tube	A. Le Grand	1877	133
Wells, Tube, for large Water Supply ..	R. Sutcliff	1877	149
Wheels, Elastic Railway	V Pendred	1864	119
Wimbledon Main Drainage and Sewage Disposal Works.	W. S. Crimp	1888	73
Worms, The Action of Marine, and Remedies employed in the Harbour of San Francisco.	J. Blackbourn	1874	111

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